ON THE

ORIGIN OF ERUPTIVE AND PRIMARY ROCKS.

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(Presented to the Natural History Society.)

On a former occasion,* I had the honor of presenting to this Society a series of papers describing the primitive formations as they occur in Norway, and comparing them with their Canadian equivalents. I then confined myself to a simple statement of the facts known regarding these formations, referring to their constituent rocks, to their structure, and to the order of their succession, but abstaining altogether from any attempt to propound a theory which might explain the various phenomena described. I subsequently † however gave a translation of a chapter from Naumann's classical *Lehrbuch der Geognosie*, wherein the various views entertained by geologists as to the origin of these formations, are plainly and impartially stated. It there appears, that although there exists an extraordinary diversity of opinion among geologists on this subject, there are two distinct and opposing theories, under one or other of which those different views may be classified. The first of these theories, and the one adopted by the majority of geologists, supposes the primitive or primary rocks to have resulted from the alteration or metamorphism of sedimentary strata. The second theory supposes them, in part at least, to represent the first solidified crust of our planet.

Although these opposing theories might with justice be respectively termed, so far as they refer to the origin of the primary rocks, the aqueous or metamorphic theory, and the igneous theory, still they must not be considered as bearing the slightest relation to the old theories adopted, and so pertinaciously

* Canadian Naturalist, Vol. VII, p. 1.

† Canadian Naturalist, Vol. VII, p. 254.

argued by the neptunists and plutonists. The question in dispute then, referred to the origin of the undoubtedly intrusive and unstratified rocks,—granite, porphyry, basalt, &c. So far however as concerns the primitive stratified rocks, Werner and Hutton both regarded them as of sedimentary origin, although they differed as to the state in which they were deposited; and Hutton alone considered it necessary to explain their crystalline condition by the metamorphic action of heat. Indeed, instead of there being any analogy between the old controversy and the present question, it happens that Hutton, the founder of the plutonic school of former days, was the originator of the theory at present prevailing of the aqueous origin of the primary stratified rocks.

On the other hand, it is scarcely possible to say who was the author of the igneous theory, although the writings in which it was propounded are of comparatively recent date. Probably among its earliest supporters was Sir H. T. De la Beche, who thus expresses himself on the subject:—"If we consider our "planet as a cooling mass of matter, the present condition of "its surface being chiefly due to such a loss of its original heat "by long continued radiation into the surrounding space, that "from having been wholly gaseous, then fluid and gaseous, and "subsequently solid, fluid and gaseous, the surface at last became "so reduced in temperature, and so little affected by the remain-"ing internal heat, as to have its temperature chiefly regulated "by the sun, there must have been a time when solid rock was "first formed, and also a time when heated fluids rested upon it. "The latter would be conditions highly favorable to the pro-"duction of crystalline substances, and the state of the earth's "surface would then be so totally different from that which now "exists, that mineral matter even abraded from any part of the "earth's crust which may have been solid, would be placed under "very different conditions at different periods. We could scarcely "expect that there would not be a mass of crystalline rocks "produced at first, which, however they may vary in minor "points, should still preserve a general character and aspect, the "result of the first changes of fluid into solid matter, crystalline "and sub-crystalline substances prevailing, intermingled with "detrital portions of the same substances, abraded by the move-"ments of the heated and first formed aqueous fluids." *

* Report on the Geology of Cornwall, &c., p. 32.

Although this language is somewhat indefinite, still the idea embodied in the igneous theory is shadowed forth in it, and on the whole this quotation may be considered as the text of the present essay. It is I believe possible to maintain, with every appearance of reason, that the Primitive Gneiss formation constitutes the first solidified crust of the originally fused globe, and that the crystalline and sub-crystalline rocks of the Primitive Slate formation are the products of a peculiar transition period, during which aqueous fluids gradually accumulated on the surface, and the latter attained a temperature approaching somewhat to that of the present day.

In attempting to show that this proposition is supported by geological evidence, I shall confine myself principally to arranging and elaborating the facts and arguments in support of it, which I have found scattered through a considerable number of geological papers and manuals. I shall also, in order to state the case with full force, be obliged to insert prefatorily much of what may be considered as mere elementary facts in physical geography and geology. I shall first refer to the evidences which we possess regarding the internal heat of our planet and its density, deducing from them certain conclusions as to the present condition of the interior of the earth. In doing so, I shall allude to the nature of certain volcanic products; and then continuing the considerations of the constitution and mode of occurrence of igneous rocks, I shall search back through the various eruptive formations for evidences of the nature of the igneous action which has taken place in former periods of the earth's history, and ultimately arrive at the consideration of the theory of the earth's original state of igneous fluidity. This theory, universally admitted by geologists, will then afford us a firm starting point for some speculations as to the process of the first solidification of the earth's crust, and the origin of gneissoid rocks. Pursuing the subject further, I shall endeavour to shew that the peculiar rocks of the Primitive Slate formation are also products of the action of the first condensed fluids on the heated crust of the earth. There are few theories whereon such a unanimity of opinion exists among geologists, as that of the originally fused condition of our planet, and few formations regarding the origin of which more uncertainty prevails than that of the primitive formations. If therefore it can be shewn to be probable that these primitive formations have merely

resulted from an originally fused globe in the process of cooling, much will have been done toward filling up a great gap in the history of the earth's development.

I. The Temperature and Density of the Interior of our Planet.

It will no doubt seem to many that the matters to be treated of in this chapter, are far beyond the limits of the subject of the present paper. Since, however, the originally fused condition of our planet, and the constitution of its mass, are at the foundation of the igneous view of the origin of the primitive gneiss formation, it would seem necessary to refer to the reasonings upon which the idea of a fused globe, and the various theories propounded regarding the structure of the interior of our planet, are based. Many of these reasonings are founded on phenomena observable at the present day, which point to the existence of intense heat and extraordinary density in the centre of the earth. Hence this proposed recapitulation of the evidences of internal heat and density may not be out of place.

Whatever may have been the temperature of the earth's surface in the former periods, it is abundantly evident that it is now altogether regulated by the sun. Since the influence of the sun's rays penetrates to some extent beneath the surface, and affects the degree of temperature there existing, it will be necessary to define the extent to which this takes place, before proceeding to advert to the influence of the subterranean heat on the temperature of the earth's crust. It is obvious that the influence of the sun's rays is exerted very irregularly, and that variations in the degree to which the surface of the earth is affected by it occur throughout the day, and annually. The diurnal variations are of course not so great as those of the year, and the latter vary of course with the situation of the point of observation. These diurnal and annual variations are less and less felt, the deeper, to a certain point, we penetrate beneath the surface. Towards this point the extremes of temperature gradually approach nearer to each other, the differences are gradually equalized, and finally they disappear completely. The depth at which this point of constant temperature exists varies with latitude and climate, and with the capacity for conducting heat which the surface possesses. In African deserts, where the sand has been found to possess sometimes a temperature of 40° to 48°

R,* the point of constant temperature is near the surface, because the annual variations are comparatively small. The average temperature of the warmest month in Singapore is 22.40° R., of the coldest month 20.6° R.† The yearly variation therefore, does not exceed 1.8° R., and consequently the point where the extremes equalize themselves must be very near the surface. In higher latitudes however, where the variations are greater, (London 11.80° R., Paris 13.50° R., New York 21.70° R.,) the point of invariable temperature lies deeper. In the temperate zone, the daily variations disappear at a depth of from three to five feet, and the annual variations at a depth of from 60 to 80 feet beneath the surface. The celebrated thermometer placed 86 feet beneath the surface in the vault of the national observatory at Paris in 1783, shews constantly a temperature of 9.60° R.‡ Since the average temperature of Paris is 8.60° R., it would therefore appear that even at this depth of 86 feet the influence of the central heat begins to make itself felt.

As early as the year 1678, the Jesuit Athanasius Kircher was informed by Hungarian miners that a higher temperature existed in the depths of mines, than on the surface of the earth, and Von Trebra, in 1785, mentions the same fact.§ Not only was practical experience of the existence of a subterranean source of heat first obtained by miners, but the first experiments made with the view of ascertaining the temperature of the earth's crust at greater depth, were instituted in mines. The results of these experiments constituted for a long time the only proofs of the increase of the temperature with the depth. It cannot be denied however that the observations made in the shafts and underground working of mines are subject to various disturbing influences, so that it would appear that at least the earliest of these observations are less to be relied upon than those from other sources. But since they shew a general coincidence they furnish, when taken in connection with other observations, a complete confirmation of the fact of the increase of temperature with the depth. The results of the experiments instituted in mines, differ in value according as they have reference to the tempera-

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* Pouillet; Muller, Lehrbuch der Physik and Meteorologie, Vol II, p. 724.

† Ibid II, 716.

‡ Quenstedt, Epochen der Natur, p. 13.

§ Ibid p. 12.

ture of the air, water or rock there occurring. Those obtained from observations made on the rock plainly deserve most confidence.* Not only in European mines, but in those of South America, Mexico, the United States, and the East Indies, observations have proved that the temperature increases with the depth, and shewn that it remains invariable at one and the same depth, provided no disturbing causes are at work. In 1740, Gensanne instituted experiments at Giromagny in the Vosges which gave the following results :— At a depth of

339 feet	the temperature was	12.5°	Centigrade.
634 "	" "	13.1°	"
948 "	" "	19.0°	"
1333 "	" "	22.7°	"

Saussure obtained the following results at Bex in the Canton Waadt, in a shaft in which no one had been for three months previously.

Depth.	Temperature.	
322	14.4°	Centigrade.
564	15.6°	"
677	17.4°	"

Similar observations were afterwards made in the mines of Freiberg by d'Aubuisson, Von Humboldt, and Von Trebra; in the mines of Cornwall by Forbes, Fox, and Barkam, and in the Anzasca valley by Fontanetti. The most comprehensive and exact observations were however those made at the instance o the government mining officials of Saxony and Prussia, in the mines of those countries. The observations in the Prussian mines led to the following results.†

1. That a decided increase of temperature takes places with increase of depth.
2. That the temperature at every greater depth is invariable, since the annual oscillations were at the most only 1°.
3. That the depth corresponding to an increase of temperature of 1°, differs extremely in different localities, varies from 48 to 355 feet, and on an average amounts to 167 feet.
4. That the temperature increases twice as rapidly in coal mines as in ore mines.

* Naumann, Lehrbuch der Geognosie, I, 49.

† Poggend. Ann; vol. xxii, 1831, p. 497.

5. That the observations did not afford data sufficiently decided for the establishment of any law as to the progression of the increase of temperature.

The experiments instituted in the Saxony mines were under th careful direction of Reich, and made with very good thermometers, sunk forty inches into the solid rock, and with every possible precaution. They yielded the following results.*

1. That the temperature increases decidedly with the depth.
2. That the temperature is invariable at every one point of observation.
3. That the average distance, corresponding to an increase of one degree Reaumur in temperature, is 129 feet.
4. That a general law with regard to the relative increase of temperature cannot be deduced from these experiments.
5. That the rock in the underground workings and in the course of time becomes somewhat cooled by the air of the mine, and that on the whole the cooling influences overbalance the heating ones.

Among other observations the following may be mentioned :— The distance corresponding to an increase of temperature of one degree was determined by:

Oldham in Waterford, Ireland, as	165	Feet.
Phillips in New Castle	100	"
Hodgkinson in Manchester	115	"
Hinzeau in Belgium	102	"
Cordier near Canneaux	111	"†

It will be observed that in the observations mentioned above, the depth corresponding to an increase of 1° varies from 92.3 to 167 feet.

Conclusive as are the experiments in mines with regard to the increase of temperature, they after all refer only to comparatively slight depths. The depths at which observations have been made in artesian wells exceed those of the mine experiments. As is well known, by means of these artesian wells, a vent is opened whereby the water of subterranean reservoirs or springs, confined

* Reich: Beobachtungen über die Temperatur des Gesteines, 1834.

† Naumann; Lehrbuch der Geognosie, I, 54.

at great depths, finds a passage to the surface. This water, having found its way from the surface into those depths, is generally subject to a very strong hydrostatic pressure, and possesses the temperature of the depth from which it is liberated. The bore-holes, by means of which these subterranean reservoirs are tapped, are especially fitted for experiments as to the temperatures of various depths, since their depth, while being bored is accurately known, and since they are always filled with water. Such experiments have repeatedly been made, and have led to the complete and incontrovertible confirmation of the fact that the temperature of every constant depth, beneath the influences of the variations of temperature on the surface is invariable, and that the temperature increases continually with the depth. The following tables contain some of the most remarkable observations of this nature.

Artesian well at Rudersdorf, near Berlin :—

Depth.	Temperature.	
380 feet	17.12°	Centigrade.
500 "	17.75°	"
655 "	19.75°	"
880 "	23.50°	"

Artesian well of Grenelle, in Paris :—

Depth.	Temperature.	
917 feet	22.20°	Centigrade.
1231 "	23.75°	"
1555 "	26.43°	"
1684 "	27.70°	"

Artesian well of Neusalzwerk, Westphalia :—

Depth.	Temperature.	
580 feet	19.7 °	Centigrade.
1285 "	27.5 °	"
1935 "	31.4 °	"
2144 "	33.6 °	"

In the artesian well at Mondorff, in the Grand Duchy of Luxemburg, at a depth of 2066 feet, a temperature of 34 ° Centigrade was even observed. We have already seen that the results of the experiments in mines, as to the depth corresponding to one degree of increase, varied considerably. The results obtained in artesian wells as to this point were much more satisfactory. The distance corresponding to an increase of 1 ° was found to be:

At Rouen	90. 8	Feet.
At Mondorff	91. 1	"
At Rüdersdorf	92. 0	"
At Neusalzwerk	92.27	"
At Grenelle	95. 0	"
At St. Andre (Eure)	95. 3	"

These results shew a remarkable coincidence, but there are others which shew extraordinary differences, such as the following:—

At La Rochelle	60. 6	Feet.
At Pitzbuhl near Magdeburg	80. 0	"
At Artem in Thüringia	120. 0	"*

These latter results, as well as those differing widely from each other, which have been obtained in mines, are not to be regarded as at all invalidating the general result. These differences may be caused by variations in the conducting capacity of the various rocks; by the neighborhood of subterranean water courses; but especially by the greater or lesser distance of the point of observation from the source of the internal heat; in other words by the varying thickness of the earth's crust.

We have thus seen that actual observations have been made as to the temperature of the crust at various depths beneath the surface, sometimes as much as 2000 feet, and the result of these has been to prove that an increase of temperature takes place with the depth, amounting on the average to about 1° Cent. for every 100 feet. We have next to enquire as to whether any increase of temperature takes place at still greater depths. We have abundant proofs that this further increase does take place, in the temperatures of the thermal springs so widely distributed over every part of the surface of the globe. These temperatures are much higher than those which have been observed in mines or artesian wells. The waters of these springs rush with extraordinary force out of the ground, from which circumstance we may conclude that they ascend from their sources, with a rapidity which does not permit them to cool very considerably in their passage through the upper and colder strata. Although we are ignorant of the exact depth from which the waters of these springs rise, we are nevertheless justified in assuming that they come from greater depths than those of mines or artesian wells.

* Naumann's Geognosie, I, 48.

The highest temperature yet observed in the latter was at Mundorff, viz,, 34° Centigrade. The following is a list of remarkable thermal springs whose temperatures exceed that just mentioned.

Spring.	Temperature.	
Pfäffers	37.2°	Centigrade.
Wildbad	37.5°	"
Barrèges	40.0°	"
Aix-la-Chapelle	44° to 57.5°	"
Bath	46.25°	"
Leuck	50.2°	"
Aix in Savoy	54.3°	"
Ems	56.25.°	"
Baden-Baden	67.5°	"
Wiesbaden	70.0°	"
Carlsbad	75.0°	"
Burtscheid	77.5°	"
Katherine Spring in Caucasia	88.7°	"
Trincheros in Venezuela	97.0°*	"

We have here a series of temperatures, from the warmest yet observed in artesian wells to that of boiling water, and it would seem not unreasonable to suppose that the differences in their temperatures correspond to differences in the depths of their sources. It is true that the neighborhood of volcanoes or of igneous rocks may heighten the temperature of springs rising from comparatively shallow depths, but it is also the case that many very hot springs occur in districts far distant from volcanic regions. Thus it is with the hot spring of Hammam-mes-Kutin, betwixt Bone and Constantine, the temperature of which is stated at from 60° to 95° Cent.; and also with the warm springs in Cape Colony, which, according to Kraus, break forth from sandstone, far from any plutonic rock.† It is clearly impossible to account for the differences in the temperatures of thermal springs in any other way than by supposing that the springs possess very nearly the temperatures of the depths from which they rise, and that the higher the temperature of the water the deeper is the source from which it springs. We are therefore justified in regarding it as fully proved that the temerature of the earth increases with the depth, until a point is

* Muller's Kosmische Physik, p. 340.

† Naumann's Geognosie, I, 306.

reached at which water boils. It is a matter of much difficulty however to determine, with any degree of precision, the depth at which this heat is attained. If we assume that the same increase of 1° Centigrade for every 100 feet depth, which takes place at the surface, continues to greater depths, the calculation is very simple. The temperature of the Mondorff artesian well was 34° Cent., at a depth of 2066 feet. If we add 100 feet for each of the remaining 66° C, we have a temperature of 100° C, at a depth of 8666 feet. It will however be shewn in a subsequent part of this paper, that we are not justified in assuming that the increase of temperature follows such a regular progression, that the rapidity with which the temperature increases, diminishes with the depth, and that consequently the depth at which a constant temperature of 100° C. reigns, is much more considerable than that above stated; that it is at least 10,000 feet, and probably even as much as 20,000 feet.* It is quite possible that under the great pressure which must exist at this latter depth the boiling point of water may be higher than 100° C., but then however, this might be it could not retain this higher temperature until it reached the surface. Because however rapidly it might ascend, its temperature would on the way decrease with the removal of the pressure, steam being at the same time generated. It is not improbable that the waters of the Geyser and the Strokkr have at their sources a much higher temperature than 100° C., and that the eruptions observable at these springs are caused by the generation of steam in the canal of egress, owing to the removal of the pressure. This view is supported by the observations made on the temperature of these springs. The water of the Geyser at the surface has a temperature of 76° to 89° C., but at a depth of twenty-two meters it is from 122° to 127° C. The water of the Strokkr is continually boiling at the surface, and has, at a depth of forty-one feet, a temperature of 114° C.† But although it is possible for water to exist at a much higher heat than 100° C, at such great depths, it is nevertheless also evident that at still greater depths, and increased temperatures, it can only exist in the form of steam. We can moreover readily conceive a depth and temperature to which it would be impossible for water to penetrate. If the temperature of the earth's crust continues to

* Naumann, Geognosie, I, 66.

† Krug von Nidda, in Karsten's Archiv für Mineralogie, &c., ix, 247.

increase with the depth, there must exist at some depth, sufficiently great, a point beyond which the rocks are heated to such an extent that before water can penetrate to them it is resolved into steam and expelled.

Beyond this point there is a long interval, regarding the increase of temperature in which, we have no direct evidence until we arrive at that furnished by the fused rock which in the form of lava is poured forth by volcanoes, which are even more widely and generally distributed over the earth's surface than thermal springs. This however supplies indirect evidence sufficient to prove that during this great interval the heat must increase with the depth, until the temperature of fused lava is reached, at which point we must suppose everything to be in a fluid state, and consequently the temperature from that point to much greater depths to continue about the same. The lavas which have been emitted by volcanoes in historic times, have been both of a trachytic and a basaltic nature, but those of the latter character seem to have predominated. Many of these doleritic or augitic lavas from very recent lava-streams have been described and analysed. They are of a comparatively basic composition, seldom contain more than 50 per cent of silica, and are much richer than other volcanic rocks in iron-oxide. The lava which constituted the stream from Etna, that destroyed a great part of Catania in 1669, had the following composition:—

Silica	48.83	
Alumina	16.15	
Protoxide of iron	16.32	34.97
Protoxide of manganese	.54	
Lime	9.31	
Magnesia	4.58	
Soda with some potash	3.45	
Potash	77	
	99.95.*	

This analysis bears a general resemblance to those of other augitic lavas. It also bears a resemblance to that of the slag produced in smelting the copper schists of Mansfeldt. According to Hoffman, the composition of the slag produced at Kupfer Kammerhütte in the first or raw smelting, is as follows.

* Bischof; Chemical and Physical Geology, ii, 235.

Silica	48.22	
Alumina	16.35	
Protoxide of iron	10.75	35.28
Lime	19.29	
Magnesia	3.23	
Protoxide of copper	75	
" " zinc	1.26	
	99.85.*	

According to Plattner, the melting point of these slags is about 1400° Centigrade.† If we suppose that the increase of temperature downward in the earth's crust progresses at the rate of 1° C. for every 100 feet, the thickness of the earth's crust may be calculated as follows. The temperature of the Mondorff artesian well was 34° C, at a depth of 2066 feet. If we add 100 feet for each of the remaining 1366° (136,600 ft.)—the temperature of 1400° would exist at a depth of 138,666 feet, (26¼ English, or 22¾ geographical miles.) However crude and uncertain this method of calculating the thickness of the earth's crust may be, it appears nevertheless to have been almost the only one hitherto employed for that purpose. It seems to have been assumed on all hands that the increase of temperature takes place in the ratio of a simple arithmetical progression. Humboldt‡ adopts the idea that "granite is in a state of fusion about "26 or 30 geographical miles beneath the surface." At another place§ he states it at "somewhat more than 20 geographical "miles ($21\frac{6}{10}$ = 25 English)." "45,000 metres=24 geographical "miles, was named by Elie de Beaumont (Geologie, edited by "Vogt, 1846, I, 32) as the thickness of the solid crust of the "earth. Bischof (Warmelehre des Innnern unseres Erdkörpers, pp, 271 and 286,) estimated it between 122,590 feet and "136,448 feet, or on the average 21⅓ geographical=24½ English "miles." The average diameter of the earth being 6864 miles, it follows from the above estimate, that the thickness of the earth's crust only amounts to about $\frac{1}{150}$th of the radius of its circumference. When we reflect on this result, it would appear that this thickness is altogether insufficient to lend to the earth's crust that stability which it now possesses. Moreover, there are other estimates than those above quoted, which give to the earth's

* Kerl. Handbuch der Huttenknude, I, 296.

† Ibid; I, p. 282. ‡ Kosmos; English edition, I, 26. § Ibid V, 169.

crust a much more considerable thickness. Cordier assuming 100 ° Wedgewood as the melting point of lava, determined the depth at which everything is in a fluid state, from his observations :—

At Canneaux, to be	148	English geographical miles.
At Littry	84	do.
At Decise	64	do.

And he finally draws the conclusion that the average thickness of the solid crust of the earth cannot well exceed 56 English geographical miles.* Sartorius von Waltershausen's estimate will be referred to when we come to take into consideration the density of the earth. Naumann remarks as follows on the subject: " the " temperature of the fused lava may certainly in the depths of " the earth be estimated as at least 2000 ° C. If the increase of " temperature follows the law of an arithmetical progression, then " such a temperature would be reached at a depth of 200,000 feet, " or nine German,(=36 English) geographical miles. But since " it is more probable that the distance corresponding to an in" crease of 1 ° Centigrade augments with the depth, we are jus" tified in assuming a much greater depth, and in supposing it not " at all impossible that the seat of the fluid lava is to be found at " a depth of twenty and perhaps even upwards of thirty geogra" phical miles (=80 or 120 English geographical miles,)"† There are not wanting observations to prove that the temperature of the earth's crust increases less rapidly towards the interior. Thus from a comparison of several observations, Fox deduced the result that within the first 600 feet, the temperature increases more quickly than in the following 600 feet. Henwood obtained similar results within the first 950 feet, and Rogers found in Virginia a notable enlargment with the depth, of the space corresponding to 1 ° increase. In the artesian well at Grenelle the temperature observed at

700 feet depth was........................	20.00 ° C.
1555 "	26.45 ° C.

The thermometer in the cellar of the Paris observatory shews a constant temperature of 11.7 ° C. Calculating from this depth of 86 feet, the distance corresponding to one degree's increase of temperature within the first 677 feet is 81.6 feet; and within the

* Naumann, Geognosie, I. 74.
† Naumann, Geognosie, I, 67.

next 792 feet, 123 feet; which figures plainly shew an increase with the depth of the distance corresponding to 1 ° C. Bischof's experiments on the cooling of large masses of melted basalt also furnish a very convincing proof that the increase of temperature takes place less rapidly at greater depths. 48 hours after casting a globe of melted basalt, having a diameter of 27½ inches, he found it to possess the following temperatures :—

In the centre..............................	153.5 °	R.
45 inches from do..........................	136.0 °	"
6.75 " " "	124.9 °	"
9. " "	109.8 °*	"

These observations also shew with increasing depth a diminution of the rapidity with which the increase of temperature takes place. They by no means furnish us however with secure data upon which to found a calculation as to the thickness of the earth's crust. Like the careful experiments in the mines of Prussia and Saxony, "a general law with regard to the increase of tempera- "ture cannot be deduced from them." They are useful in so far as they prove the inaccuracy of all estimates of the earth's thickness founded upon the arithmetical progression of the increase of temperature, and justify the supposition of Naumann, that the crust of the earth may have a thickness of upwards of 120 English geographical miles.

There is however yet another estimate of the thickness of the earth's crust, the consideration of which will lead us to refer to the various views entertained as to the constitution of the interior of the earth. This estimate is thus referred to by Naumann: "W. "Hopkins has adopted a peculiar method for the solution of "this problem. By very acute observation and reasoning on the "nutation of the earth's axis, and the precession of the equinoxes, "he finds that these two phenomena must come out with different "values according as the earth is solid throughout, or fluid "throughout, or solid externally and fluid internally; in which "latter case different thicknesses of the solid crust will produce "different results. It is certainly the case that in order to a cor- "rect estimate, the values of two important elements are necessary, "which are as yet unknown, viz., the condensing action of pres- "sure, and the expanding action of such high temperatures. "Nevertheless, Hopkins has attempted to answer the question ap-

* Naumann, Geognosie, I, 63.

" proximately, and gained the result, that according to the known " values of the nutation and precession, the thickness of the solid " crust cannot be less than one fourth or one fifth of the radius " of the earth and must at least amount to 172 to 215 " German geographical miles (= 688 to 860 English geogra- " phical miles.) Such a thickness of the earth's crust seems indeed " to stand in the necessary relations to the stability of the exterior " surface of the earth, but also almost completely to exclude the " possibility of a communication with the interior of the earth, " which is really so decidedly shewn to exist by varied volcanic " phenomena. Hopkins also adopts the view that with such a " thick crust a direct communication is impossible between the " interior of the earth and the surface. In order therefore to " explain the phenomena of volcanoes, he supposes the existence " of very large cavities here and there within the solid crust, " which are filled with easily fusible materials, still in a liquid " state, and which resemble colossal bubbles, enclosing whole seas " of fused substance.* Elie de Beaumont and others, on the other hand, entertain the view that spaces were formed between the solid crust, and the fluid centre which, at least in earlier geological periods, caused partial depressions of the earth's crust, and which are still to be considered as the real laboratories of volcanic activity.

Somewhat allied to Hopkins's supposition is Bunsen's theory, which rests upon certain ascertained facts with regard to the composition of igneous rocks generally, but more especially to that of lavas. Bunsen supposes the existence in the interior of the earth of two enormous reservoirs of fused matter having each a different composition, and from the amalgamation of which all the known varieties of trachytic and doleritic rocks result. This theory is based upon two series of analyses of Icelandic lavas, the one comprising, according to Bunsen, those richest in silica (trachytes), the other those containing the largest amount of bases, (trap rocks, basalts and basaltic lavas). The first series of analysis comprised those of the following rocks:—

1. Trachyte from Baula.
2. Do from Kalmanstunga.
3. Do from Langarfjäll near the Geyser.
4. Trachyte from Arnar Knipa on the Laxa.
5. Do from Falklaklettur near Kalmanstunga.

* Naumaun, Geognosie, I, 75.

6. Trachyte from Krabla.
7. Obsidian from Krabla.

	1.	2.	3.	4.	5.	6.	7.
Silica	75.91	77.92	75.29	78.95	76.42	76.38	75.77.
Alumina	11.49	12.01	12.94	10.22	9.57	11.53	10.29.
Ferrous oxide	2.13	1.32	2.60	2.91	5.10	3.59	3.85.
Lime	1.56	0.76	1.01	1.84	1.53	1.76	1.82.
Magnesia	0.76	0.13	0.03	0.14	0.20	0.40	0.25.
Soda	2.51	4.59	2.71	4.18	5.24	4.46	5 56.
Potash	5.64	3.27	5.42	1.76	1.94	1.88	2.46.
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The mean of these analyses is:

Silica	76.662	
Alumina	11.150	
Ferrous oxide	3.071	
Lime	1.469	23.338
Magnesia	0.274	
Soda	4.178	
Potash	3.196	
	100.00.	

This Bunsen assumes to be the composition of the normal trachytic mass, which occupies one of the reservoirs of his theory. The second series of analyses comprised those of the following rocks:

1. Trap rock from Esiaberg.
2. Trap from Vidoe.
3. Light fine grained basaltic rock from Hagafgëll on the right bank of the Thiorsa.
4. Basaltic rock from Skardsfjäll.
5. Lava from an old stream of Hecla.
6. Rock from the precipice of Almannagjö near the lake of Thingvalla.

	1.	2.	3.	4.	5.	6.
Silica	50.05	47.48	49.17	47.69	49.37	47.07.
Alumina	18.78	13.75	14.89	11.50	16.81	12.96.
Ferrous oxide	11.69	17.47	15.20	19.43	11.85	16.65.
Lime	11.66	11.34	11.67	12.25	13.01	11.27.
Magnesia	5.20	6.47	6.82	5 83	7.52	9.50.
Soda	2.24	2.89	0.58	2.82	1.24	1.97.
Potash	0.38	0.60	1.67	0.48	0.20	0.58.
	100.00	100.00	100.00	100.00	100.00	100.00.

The mean of these analyses is:

Silica	48.472	
Alumina	14.781	
Ferrous oxide	15.383	
Lime	11.866	51.528
Magnesia	6.890	
Soda	1.957	
Potash	0.651	
	100.000	

This Bunsen assumes to be the composition of the normal pyroxenic mass, which fills the second supposed reservoir of igneous fluid material in the centre of the earth. He further argues that all volcanic rocks, that is to say rocks belonging to the trachytic, basaltic or lava eruptive formations, may be regarded as mixtures of these two fluid materials, and shews that after merely determining how much silica they contain, it can be ascertained by calculation in what proportions these two materials from the different reservoirs are present. With regard to this theory Sartorius von Waltershausen remarks: "It is evident "that this average (that of the normal pyroxenic mass) can "just as little be regarded as the limit on the basic side, as the "so called normal trachytic average on the other. Nor is it "apparent why the above-mentioned six analyses only were used "in computing the average, while others, such as lava from Thiorsa, "and trap rock from Esia were neglected."*

Mr. Sterry Hunt, who as we shall see, rejects altogether the theory which derives the eruptive rocks from a portion of the primitive fused mass of the globe, and supposes them to consist of altered, fused, and displaced sediments, (Can. Naturalist, Dec. 1859], remarks, with regard to Bunsen's hypothesis, that the calculated results as deduced from the volcanic rocks of Hungary and Armenia, often differ considerably from those obtained by analysis; a result which will follow, when as is often the case, different triclinic feldspars replace each other in the pyroxenic rocks. He also shows that the composition of certain eruptive rocks, like phonolites, (which are highly basic, and yet contain but little lime, magnesia, or iron-oxide) is such that they cannot be derived from either of the magmas of Bunsen.

* Ueber die vulcanische Gesteine in Sicilien und Island, und ihre ubmarine Umbildung; Göttingen, 1853.

Naumann quietly remarks that the theory of the two separate reservoirs is surely not yet sufficiently proved, and characterises Von Waltershausen's theory of the constitution of the interior of the earth as more natural, and more in accordance with our knowledge regarding the probable condition of the earth's centre.* This theory, which the author first promulgated in the work from which we have just quoted, deserves to be better known. It is principally founded upon certain reasonings deducible from the density of the earth, and for this reason a recapitulation of what is known concerning this point may not be inappropriate here.

In 1776 Hutton and Maskelyne determined the density of the earth from the attraction exerted on the plumb line by the mass of the mountain Schiehallion in Perthshire. Assuming the mean of specific gravities of the three principal rocks, of which it consists, viz., mica slate, limestones, and quartzite, to be the density of the whole mass, they calculated from their experiments the density of the earth to be 4.713.

The density of the earth has also been determined from observations on the oscillations of the pendulum on high mountains. In this way Carlini found from experiments on Mount Cenis the density of the earth to be equal to 4.37, which value was however raised by Schmidt to 4.837, by correcting an error in Carlini's calculations.

The most exact method however yet applied towards determining the density of the earth is that by means of the torsion balance invented by the Rev. John Mitchell, and used after his death by Cavendish. In 1798 this philosopher communicated to the Royal Society the result of his experiments with this apparatus. From seventeen sets of experiments he deduced twenty-three results, from the mean of which he computed the density of the earth to be equal to 5.48. Bailly, correcting an error in Cavendish's calculation, makes it 5.45. Schmidt, likewise, after a revision of Cavendish's computations, alters the result of these to 5.52. In 1837, Reich of Freiberg performed a series of experiments with the same apparatus, much improved in various particulars. Fifty-seven experiments were made in all, from which fourteen results were deduced, the mean of which makes the density of the earth equal to 5.44. In 1848 Baily, at the request of the Astronomical Society, undertook to repeat Cavendish's experiments.

* Lehrbuch, ii, 1101.

It was not however until 1841 that the apparatus was modified and improved to such an extent as to give the most satisfactory results. The experiments with the perfected apparatus were continued till May, 1842, when the result was arrived at that the mean density of the earth is 5.66. From this enumeration of all the experiments which have been made for the determination of the mean density of the earth, it will be evident that the result as given by Baily, is one of the most unequivocally established scientific facts. Not only is there (considering, the different times and circumstances when they were instituted) a surprising coincidence in the results obtained by the torsion balance, but these are confirmed in the mean by the results obtained from the less accurate methods first described.

If we compare the mean density of the earth, as found by Baily, with the specific gravities of a few well known minerals, we find that it equals the density of copper glance, and exceeds that of magnetic iron ore, iron pyrites, variegated copper ore, and copper pyrites. If we moreover compare it with the specific gravities of these minerals or rocks which constitute the great bulk of the earth's crust, we find it to possess twice as great a density. The inference is unavoidable that the centre of the earth is much more dense than its crust, and is also possessed of a higher density than that of the earth's whole mass. This conclusion has, nevertheless, been received by many with grave doubts. It has even been supposed that the increased density at the earth's centre is attributable to the increased density which the substances there existing acquire from the enormous pressure of the superincumbent mass. This explanation rests upon the groundless supposition that solids may be compressed to an indefinite extent. It further neglects the very essential circumstance that the attraction exercised on any material point in the interior of the earth is only exerted by that part of the earth which lies within the spherical surface passing through the given point, and that the mass of the earth outside of this surface exercises no attracting influence on it. Since therefore the weight of a body is determined by the sum of the attracting forces acting on it, it follows that the weight of one and the same body must be less in the interior of the earth than on the surface.* Moreover, it is very certain that an extraordinarily high temperature exists in the interior of our planet, which

* Naumann, Lehrbuch, i, 40.

must cause the bodies existing there to expand, and which must thus neutralise much of the compression exercised on these bodies by the masses lying above them. Finally, it seems that the compressing powers of the superincumbent masses have been somewhat over estimated. The crust of the earth must be regarded as a self-supporting arch, exercising a pressure only on the elastic fluids occurring in it, and not as resting or floating on the fluid interior. The latter has then only to bear the weight of the columns of lava which may exist in the interior of volcanoes, and which is certainly not inconsiderable. From these considerations it would seem perfectly correct to suppose that what the crust of the earth wants in density as compared with the whole mass of the planet, must be made up by the centre.

Naumann finds that assuming the average density of the earth's crust to be 2·5, and the increase of density to take place according to arithmetical progression, the density of the centre would be 8·5, consequently considerably more than the specific gravity of iron, and almost equal to that of cobalt. A similar calculation is the starting point for the theory already mentioned of Sartorius Von Waltershausen. He finds the mean of the specific gravities of orthoclase, albite, quartz, crystalline limestone and mica to be 2·66, and assumes this as an approximation to the mean density of the outer crust. Calculating, first, three fifths of the total volume of the earth to possess this specific gravity, he finally computes the density of the centre to be 9·585. He moreover calculates the densities which exist at various depths beneath the earth's surface. These depths, converted into English geographical miles, with their calculated densities are as follows:—

Miles from surface.	Density.	
0	2·66	
34	2·79	
68	2·93	
103	3·07	Lime.
137	3·20	Magnesia.
171	3·34	
206	3·47	
240	3·60	
274	3.72	
309	3·85	
343	3·99	Alumina.
686	5·15	Iron-oxide.
1029	6·29	Tellurium, Chromium.

Miles from surface.	Density.	
1372	7·09	Zinc, Iron, Antimony
1716	7.85	Cobalt, Steel.
2059	8·47	Uranium, Nickel.
2402	8·96	Copper.
2745	9·31	
3088	9·51	
3432	9·59	Bismuth, Silver.

The theory maintained by Sartorius Von Waltershausen regarding the constitution of the earth's interior, (in opposition to Bunsen's hypothesis of the two separate reservoirs of acid and basic molten rock,) is indicated by the above series of calculated densities. He supposes that from the interior of the earth's crust to its centre a gradual increase of density takes place in the fluid mass, or that this fluid mass in its present condition, as in former ages, consists of a series of concentric layers of molten matter, which are the denser the nearer they approach to the earth's centre. Instead therefore of regarding trachytic and basaltic lavas as the products of the two separate reservoirs, he considers them as the products of two different concentric layers, or as originating from two different levels in the fluid mass, the basaltic lava occupying the lower layer or level, and the trachytic floating above it; the one, both as regards chemical composition and density, graduating into the other. Von Waltershausen found the mean specific gravity of seven different Icelandic trachytes to be 2,524, while that of ten different basaltic lavas amounted to 2,911. With the increase of specific gravity towards the centre, Von Waltershausen supposes also an increase in the basic constituents of the molten rock, a change from a purely feldspathic material, yielding trachytic rocks mainly composed of feldspar, to one much richer in lime, magnesia and iron-oxide, and yielding dolerites consisting of feldspar, hornblende or augite, and in smaller quantity magnetic iron ore. He further supposes that beneath this doleritic material the quantity of iron-oxide, capable of producing the last named mineral, goes on increasing, and that ultimately a point is reached from which to the centre metallic elements alone exist. In further reasoning as to the condition of this metallic centre, Von Waltershausen takes into consideration the influence of the superincumbent pressure upon the fusing point of the metals. The following is a translation of his remarks on this subject: "For sometime past Bunsen has devoted his at-
'tention to this subject, and described (in Poggendorff's Annalen,

" LXXXI, 562) a series of experiments from which it appears " that the temperature of the fusing point of various substances " increases with pressure. These experiments have it is true only " been made on two easily fusible organic substances spermaceti " and paraffine. The melting point of the former is under a " pressure of 100 atmospheres raised 2.1° Centigrade, while that " of paraffine is raised 3.6° Centigrade. It cannot be doubted that " a heavy pressure acts in a similar manner, although possibly not " to such an appreciable extent, upon solidifying masses of silicates. " If the point of fusion of the latter, under a pressure of 100 atmos- " pheres, only increased 1° Centigrade, this would still be sufficient " to explain many important points in geology, and especially in " the formation of crystalline rocks. Although the law of the " dependance of the point of fusion upon pressure is far from " being known, the observations of Bunsen already mentioned " have incited me to enquire as to what pressure, on the basis of " the increase of density already mentioned, may be expected to " exist at any given point in the interior of the earth. If we " imagine the whole globe to be in a fluid condition, the following " pressures would be experienced at the respective depths men- " tioned.

Depths in miles.	Pressure in atmospheres.
34	17138
68	34591
103	53070
137	72195
171	92432
206	113180
240	134660
274	156840
309	179680
343	203320
686	471680
1029	786080
1372	1125690
1716	1468000
2059	1701500
2402	2297500
3088	2441900
3432	2492600

" If it is the case that the fusing point of metals (of which un- " doubtedly the greater part of our planet consists,) increases with " increasing pressure, then the question arises as to whether under

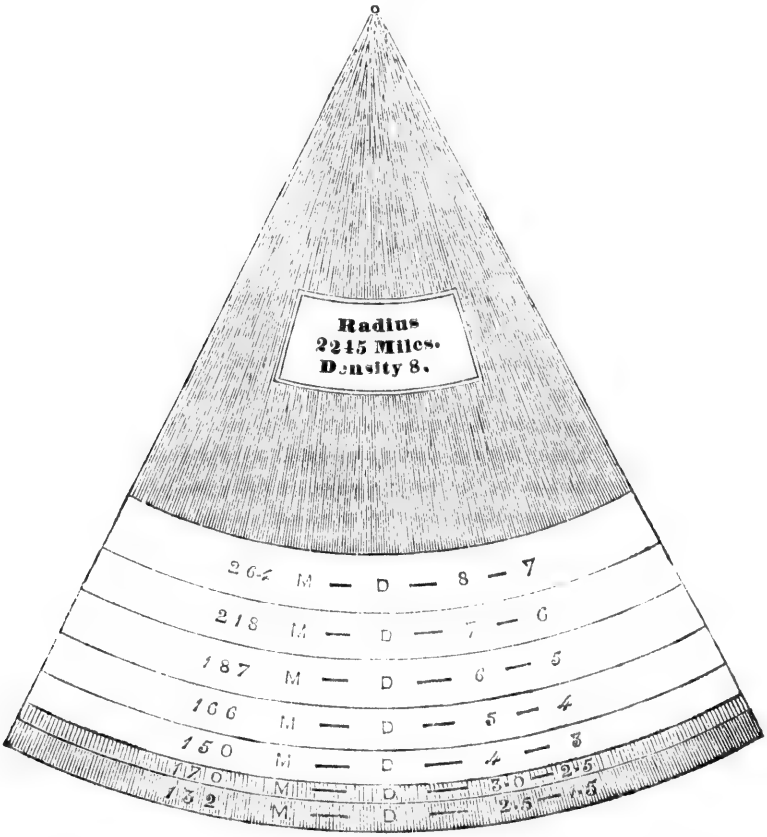
"such enormous pressures as those above calculated, even with "the high temperatures which we have to expect in the interior "a fluid condition is conceivable. The hypothesis of a solid "metallic nucleus in the interior of the earth has nothing con- "tradictory in it, and indeed the phenomena of terrestrial mag- "netism would appear to confirm this view. It is not to be "doubted that the so-called magnetic storms have their seat in "the atmosphere, or perhaps over it, and that the diurnal and "secular variations of the magnetic elements are only to be "sought in the exterior solid or solidifying crust of the earth. "If the seat of the greater part of the terrestrial magnetic "power is in the earth's crust, then we must suppose such a dis- "tribution of the magnetic fluid in it, as if on the average eight "hard steel bars weighing one pound each, magnetised to the "highest power, were present in every cubic metre. According "to geological observation, however, we can scarcely suppose the "seat of the magnetic power to rest in the earth's crust, since it "does not seem to possess either a very great thickness, or a "very intensive magnetism. According to an approximative cal- "culation which my friend W. Weber has made, a globe of the "hardest steel, magnetised to the highest degree, and having a "diameter of nearly 476 (English) geographical miles, situated "in the centre of the earth, would be able to produce the mag- "netic phenomena which we observe on the earth's surface. In "reality however these suppositions are not reliable, since we can "neither expect to find hard steel nor a perfect magnetism in "the centre of the earth. With less favorable circumstances "than those above supposed, it would be necessary to assume the "existence of a much larger solid globe in the interior of the "earth in order to account for the magnetism on its surface. "The radius of this globe would possibly extend far beyond the "point at which, according to the calculations already mentioned, "a density equal to that of metallic iron exists."

In whatever degree Von Waltershausen's method of determining the earth's density at its centre, may be looked upon as uncertain, it is scarcely possible to regard his theory of the gradual increase of density as otherwise than very reasonable. Indeed since it is certain that the centre of the earth is much more dense than the surface, it is scarcely possible to conceive how the increase can take place otherwise than gradually. Moreover Laplace deduced a similar result from his investigations

regarding the decrease of gravity from the pole to the equator. It appears however that Sartorius Von Waltershausen's estimate of the average specific gravity of the constituents of the earth's crust at its surface is too high, since it is well known that the land only occupies one-fourth of the earth's surface, and that the sea has sometimes a depth of more than 27,600 feet. It may probably be assumed with some degree of reason that the average specific gravity of the first few thousand feet of the earth's crust below the level of the sea, does not exceed 1.5. With regard to the metals constituting the earth's centre, it will probably be admitted that they exist there somewhat in the same proportion as they occur on the surface, that consequently iron constitutes by far the greater portion of the central mass. This supposition seems confirmed by the fact that among the gaseous products emitted by volcanoes, chloride of iron is very abundant, while traces only of the chloride of lead and copper have been detected. Since further, meteoric iron may be supposed to come from bodies having a common origin with our earth, their composition might be supposed to afford a clue, however slight, to the composition of the metallic centre of the earth. It would therefore seem not unreasonable to suppose that this centre is mainly composed of metallic iron, combined with copper, cobalt, nickel, lead, and perhaps silver, gold and platinum in comparatively small quantity, and that its specific gravity may be estimated on account of this admixture of heavier metals at 8.0 (Sp. gr. of malleable iron 7.78; cast iron, 7.1 to 7.5.) If we assume 1.5 as the density of the earth's surface, and 8.0 as that of its centre, we must also—since the average density of the earth is 5.56—suppose the existence at the centre, of a globe of metallic matter having a radius of 2245 English geographical miles. Assuming further a gradual increase of density from the surface of the earth to the surface of this metallic globe, we may calculate that at a depth of 132 miles the density of trachytic lava is reached, (2.5), and at 202 miles the density of doleritic lava is slightly exceeded (3.0). According to this calculation therefore the crust of the earth has a thickness of from 132 to 202 miles, a result somewhat exceeding Naumann's estimate. Calculating in the same way we further find that from a depth of 202 miles to that of 352, molten rock would exist having a specific gravity of from 3.0 to 4.0, and containing much more basic matter and iron-oxide than any rock now visible on the surface. At a depth of from

352 to 518 miles, substances may exist having a density of from 4.0 to 5.0; such as magnetic iron ore, ilmenite, copper, iron, and magnetic pyrites, variegated copper ore, sulphuret of antimony, and perhaps antimonio-sulphurets. From 518 to 705 miles in depth, substances may be present having a specific gravity of from 5.0 to 6.0 such as iron pyrites, millerite, and copper glance. Deeper still, and until a depth of 923 miles, a density of from 6.0 to 7.0 may be supposed to exist, and consequently arsenio-sulphurets of iron, cobalt and nickel, such as arsenical pyrites and speiss-cobalt, cobalt glance, and tesseral pyrites to be present. Between this depth of 923 miles, and that of 1187 miles, where according to the calculation already mentioned, the surface of the metallic globe may be found, we may suppose a density of from 7.0 to 8.0 to exist, and more or less pure arseniurets, such as the purest speiss-cobalt, arseniurets of copper and nickel, &c, to be present. It will be evident that in calculating the results above given, I have only been endeavouring to develope Von Waltershausen's theory, and in some measure to correct his results. I say correct them, because in one instance assuming the sp. gr. of the surface as 2.66, he arrives at the result that the thickness of the earth's crust does not exceed 67 English geographical miles. So far as regards the composition of the various concentric layers deduced from their specific gravities, I may remark that I have observed a similar succession to that above indicated, manifest itself in smelting cobalt ores. This operation is carried on at Modum in Norway, where on drawing the metal from the furnace there are formed in the crucible receiving it, four different layers of material, which from the surface downwards, are as follows, viz.: Slag, containing about 60 per cent. of lime and oxide of iron; 2nd, sulphurets of copper, iron and cobalt; 3rd, Arseniosulphurets of iron and cobalt, graduating into 4th, impure metallic iron, malleable and containing cobalt. The accompanying sketch shows part of a section of the earth, exhibiting the size of the central metallic globe, the thickness of the concentric layers, and of the solid crust according to the above calculations. As to whether the metallic globe in the centre is in a solid state, there would appear to be good grounds for this supposition, because apart from the consideration that the solidifying point rises with the pressure, it is well known that in many smelting furnaces, metallic iron can accumulate in the bottom, while the slag maintains its fluidity and runs perfectly free from the furnace. Mr. Sterry

Hunt inclines also to the supposition that the centre of the earth is solid, although he is of opinion that the fluid matter resting above it is altogether of sedimentary origin, and is in a state of igneo-aqueous fusion. He remarks "that beneath the outer crust of sediments, and surrounding the solid nucleus, we may suppose a zone of plastic sedimentary material adequate to



explain all the phenomena hitherto ascribed to a fluid nucleus." (American Journal of Science for May, 1861.) If, further, iron, when fused loses its magnetic power, and the phenomena of magnetism on the surface of the earth can be explained on the supposition that the metallic centre has assumed the solid form, then this supposition would appear to be very reasonable indeed. It would of course be impossible to assume that the metal have not only

solidified but also cooled to such an extent as to be capable of being magnetised to the most powerful degree. On the contrary, we must suppose them to be still very considerably heated, and consequently to possess but feeble magnetic properties. According to Humboldt, "all magnetism is certainly not lost until we "arrive at a white heat, and it is manifested when iron is at a "dark red heat." * The feeble magnetic power of the metallic globe would however be amply compensated for by its enormous size.

The possibility of the existence of such a metallic centre having been once admitted, the field opened for further reasoning as to the influence which cosmical bodies may exert upon its position, and consequently upon that of the earth's centre of gravity, is very wide indeed. That these changes may affect the hhenomena of volcanic eruptions, I shall endeavour to shew in Part II. of this paper. In the meantime it may be remarked that there exists a decided connection between magnetic, and volcanic phenomena. In the year 1767, Bernouilli observed that during an earthquake the inclination decreased half a degree, and Father de la Torre remarked that during an eruption of Vesuvius the declination varied several degrees. On the 18th April, 1842, at ten minutes past nine, Kreil in Prague observed that the needle received a very sudden stroke, and the same oscillation in the same direction was observed at the same instant by Cella in Parma, and Lamont in Munich. Shortly afterwards it was ascertained that exactly at the same minute a violent earthquake had been felt in Greece.† From the irregularities in the course of the magnetic curves, Lamont regards it as in the highest degree probable that the seat of terrestrial magnetism is to be sought in a compact nucleus which lies under the earth's crust. Müller is of opinion that the magnetic variations and oscillations can be most simply explained by considering terrestrial magnetism as dependent on electric currents which pass through the nucleus in ever varying direction and intensity.‡

That the magnetic variations stand in connection with the movements of certain of the heavenly bodies is a well ascertained fact. Sabine came to the conclusion that the disturbances belong

* Humboldt's Cosmos, English Edition, I, 183.

† Müller's Kosmische Physik, p. 497.

‡ Ibid 98.

"to a special kind of periodically recurring variations, which "follow recognizable laws, depend upon the position of the sun "in the ecliptic, and upon the daily rotation of the earth round "its axis, and further ought no longer to be designated as irreg-"ular, since we may distinguish in them, in addition to a special "local type, processes which affect the whole earth."* The hypothesis of a metallic centre would seem to be capable of forming the connecting link between the magnetic and astronomical phenomena here referred to. The relation of the sun to the earth and the revolution of the latter on its axis, would naturally effect a change in the positition of the metallic globe in the centre of the earth, which change might alter the direction of the electric currents through the earth's crust, and these again the position of the needle. Thus it seems not at all unreasonable to adopt the theory of a metallic centre, since it alone is capable of affording a solution of many problems in geology, magnetism and astronomy, and since it is capable of uniting harmoniously and explaining the most varied natural phenomena.

II. The eruptive formations.

In referring to these formations, it will be impossible altogether to avoid mentioning many matters which are very generally known regarding them. Still the connection of eruptive rocks on the one hand with the constitution of the interior of the earth as adverted to in the last chapter, and on the other hand with certain s.aty modifications of themselves, will be kept in view as much as possible. The rocks of these eruptive formations possess, as is well known, characters which distinguish them sharply from rocks of sedimentary origin. While the latter have been made up of the debris of rocks pre-existing on the earth's surface, the eruptive formations have derived their material from beneath the earth's crust. Hence they have been respectively termed by Humboldt exogenous and endogenous rocks. The eruptive rocks are more or less crystalline, generally but not always unstratified. The sedimentary rocks possess opposite characters. Each eruptive rock is in a high degree homogeneous, and shows nearly the same characters and composition throughout its whole mass. This is much less the case with sedimentary rocks. The eruptive rocks occur in very irregular forms, as enormous irregular masses, (typhonische stöcke) covers or caps (Kuppen or Decken), veins, streams and

* Humboldt's Cosmos, v, 138.

layers. Sedimentary rocks occur only in the latter form. Eruptive rocks are totally destitute of fossils, and their ages are determined by the relations of contact which exist between them and sedimentary rocks. Fossils constantly occur in the latter, and constitute the principal means of determining their age. Eruptive rocks resemble in the mode of their formation the slags which run out of smelting furnaces; sedimentary rocks the slimes deposited in stamp-works and allowed to consolidate.

The eruptive formations have been arranged in the order of their antiquity by Naumann as follows:

1. The granulite formation.
2. The granite do.
3. The syenite do.
4. The greenstone do.
5. The porphyry do.
6. The melaphyr do.
7. The trachyte do.
8. The basalt do.
9. The lava do.

This arrangement is however general and approximative. Not only do the rocks of these formations in their lithological characters graduate into each other, but the latter part of one formation may have been erupted simultaneously with the earlier rocks of the succeeding one. Thus trachytes and basalts are almost of contemporaneous origin, and porphyries have been protruded through the earth's crust in the same periods as certain greenstones and melaphyrs. I shall therefore class several of these formations together and refer to them in the following order:

1. Trachyte, Basalt, and Lava. The volcanic formations of Naumann.

2. Porphyry, greenstone and melaphyr, } The plutonic formations of Naumann.
3. Granite, syenite, and granulite, }

Trachyte, Basalt, and Lava. I have already adverted to the distribution of volcanoes as constituting a proof of the existence of a molten zone betwixt the central metallic globe and the crust of the earth. I do not deem it necessary to enlarge much upon this point. As Naumann remarks: "Volcanoes exist in every part of the earth, under every latitude, under the equator and near to the poles, in the torrid as well as in the temperate and frigid zones. They are confined to no climate, because in Iceland

Kamschatka and the Aleutian Island, between a latitude of 50° and 66° they exist as numerously as in the Sunda isles, Galapagos, and in Quito between 0° and 10° lat. But we find them especially frequent on the coasts of continents or rising out of the depth of the ocean, proving that there the conditions are especially present which are necessary to their development and activity. From all this we may conclude that the material cause of vulcanism is present everywhere beneath the earth's crust, although it may only have been able to break out along certain lines and at certain points." By means of volcanoes and the subterranean canals connected with them, a communication is established between the molten zone beneath the earth's crust and the atmosphere. This communication is liable to be interrupted by various circumstances, and when this is permanently the case the volcano is extinct. But even the active volcanoes are far from being continually in a condition of violent eruption; their usual activity is rather of a very temperate character, and F. Hoffmann very correctly remarks that the energetic eruptions are more the exception than the rule. Volcanoes in a state of rest exhale steam and other gases, and it is even the case that a quiet effusion of lava may take place unaccompanied by any extraordinary phenomena. Generally however the ascent of the lava in the canal and crater of the volcano is the immediate cause of all the sublime effects and terrible devastations, which accompany and follow volcanic eruptions. It is still a matter of doubt among philosophers as to what is the real cause of the ascent of the lava from its home in the depths of the earth. The oldest hypothesis is that which attributes the force which expels the lava to highly compressed steam, resulting from the access of water, and especially of sea water, to the regions filled with igneous fluid beneath the earth's crust. In later times this view has been adopted by very many philosophers such as Gay Lussac, Von Buch, Angelot, Bischof, and Petzholdt. On the other hand, Humboldt does not at all regard the problem as completely solved,* and Naumann does not consider it probable that the expansive force of the steam derived from sea-water is the cause of the ascent of the lava, although he considers it as quite certain, that sea and other water obtains access through the eruptive canals of volcanoes to very great depths and on the ascent of the lava plays a very important part in the phenomena of volcanic eruptions. Naumann's view so far as re-

* Cosmus I, 243.

gards the part played by water seems very reasonable. We can readily conceive that it would be difficult for water, even under considerable pressure, to obtain access by means of fissures or otherwise through the solid crust of the earth to the melted mass beneath. As previously remarked, it would be impossible for it to penetrate the highly heated rocks constituting the inner part of the earth's crust. But it would seem very possible, especially in those volcanoes situated on the coasts of continents, for water to obtain access to great depths in the craters and subterranean canals. As to the cause of the rise of lava in these, Naumann propounds the following theory:

"The solidified crust encloses the fluid interior of our planet, and at their junction the same solidifying process by which the crust of the earth was formed, must still be going on. Because however imperceptible the radiation of the internal heat may now be, it still continually takes place although in a lesser degree; and it cannot be doubted that on the inner side of the earth's crust fluid matter is continually assuming the solid form. It is indeed the case that the greatest number of fluid bodies experience a diminution of their volume, and only a few of them, such as water and bismuth, expand while solidifying, but we must reflect that the relations as to density of the bodies existing in the great depths of the earth where vulcanism has its seat, must be essentially different from those which they possess on the surface, where we can experiment with them. The pressure of the superincumbent masses must compress the materials existing at these depths. But fluid bodies are gifted with a much greater degree of compressibility than solid bodies, and therefore it can easily happen, that the most and perhaps all fused material which solidifies on the inside of the earth's crust experiences in this solidification an increase in its volume. The unavoidable consequence of this can be no other than that during this slowly progressing solidification a diminution of the capacity of the earth's crust takes place, that consequently the the space enclosed by it and filled with fused material is contracted. The next consequence will be, that a part of the fluid material will be pressed up sometimes through one and sometimes through another volcanic canal, until the weight of the column of lava equalizes the pressure in the interior. In this way the first conditions are given by means of which volcanic eruptions become possible."* The objections to this theory lie in the following

* Lehrbuch I. 289.

considerations. The difference in the compressibility of fluid and solid bodies does not seem to be very considerable. Water is but slightly compressible. According to Oerstedt, the compression produced by a pressure of 2000 atmospheres amounts only to 1-12th.,* and one would suppose that fluid lava would be even less compressible than water. The decrease of compressibility which may accompany solidification would therefore seem inadequate to the production of such stupenduous effects as are observable during volcanic eruptions. Further, if this were the cause of the ejection of the lava, the latter would be poured forth only by volcanoes of inconsiderable height, but by these simultaneously. Its ejection would also keep pace with the very slow and gradual solidification in the interior, and violent volcanic paroxysms would not occur.

Sartorius Von Waltershausen likewise assumes that expansion takes place, but he does not attribute it to the mere difference in the compressibility of the igneous material before and after solidification. He supposes that the expansion takes place in the act of crystallization, i. e. while the various minerals form and separate themselves from the fluid magma.† He fails however to adduce any conclusive evidence in support of this supposition, which it might be possible to sustain, in the event of its being possible to show that melted rock rapidly cooled to a fine grained crystalline mass, had a lesser specific gravity than the same slowly cooled and distinctly crystallized. He indeed shows that the specific gravities of the minerals which result in the cooling of igneous rocks, are invariably less than those which result in calculating their specific gravities from the quantities and densities of their constituents; as the following instances show:—

	Density. by experiment.	Density. from calculation.
1. Anorthite from Selsfjäll	2.700	3.225
2. Labradorite from Egersund	2.705	3.212
3. Orthoclase from Baveno	2.555	2.935
4. Augite from Monte Rosso	2.886	3.208
5. Hornblende from Ætna	2.893	3.447
6. English crown glass	2.487	2.721
7. Guinand, Flint glass	3.770	5.640
8. Bohemian glass	2.396	2.735

* Gmelin, Hand-book of Chemistry, II. 62.

† Uber die Vulcanishe Gesteine, etc., p. 333.

But this does not prove that a fused silicate, the constituents of which are already in chemical combination with each other, experiences a diminution of density or increase of volume in cooling and crystallizing. The only instance of the cooling of a fused silicate, which has been made the subject of observation so far as regards density, is the formation of Reaumur's porcelain from glass, but this goes rather to prove the opposite of Von Waltershausen's theory. Many kinds of glass, after exposure for several hours to a heat at which they become soft, pass into a condition resembling porcelain, become opaque, doubtless from the separation of fine particles, whose composition differs from the mass. The resulting Reaumur's porcelain is specifically heavier than the glass from which it is prepared. Moreover, this substance when again fused and *rapidly* cooled yields an enamel, the specific gravity of which is to that of the substance before fusion as 2,625 is to 2,801.* From this it would appear that instead of an increase a diminution of volume takes places in the slow cooling or crystallization of fused silicates.

If we reject both of the hypotheses just mentioned, the only explanation left, whereby the ascent of the lava column may be accounted for is that which is regarded as the cause of the more wide-spread earthquakes, viz. the fluctuations of the surface of the fluid interior of the earth.† While those earthquakes which occur simultaneously with volcanic eruptions, and in volcanic districts, may be considered as a consequence of the lava rising in the volcano, the same can scarcely be said of those earthquakes which occur in the midst of continents far distant from any volcanic region. According to Naumann, the most probable cause of these "plutonic" earthquakes is "a fluctuation of the surface of the "fluid kernel of the earth, commencing from a line or a point, "and progressing according to the laws of the motion of waves." The cause of such fluctuations he leaves undecided, but in commenting upon von Hoff's, Merian's and Perrey's investigations as to the greater frequency of earthquakes in certain seasons of the year he propounds a question, the consideration of which would seem to yield the most important results. The investigations referred to established the fact that in the northern hemispheres earthquakes are of greater frequency in winter than during any other season. Von Hoff found that of the 115 earthquakes which, during the ten years

* Gmelin III, 385.

† Naumann: Lehrbuch, I, 291.

from 1821 to 1830, had been experienced in that part of Europe lying north of the Alps, 21 had occurred in summer, 34 in autumn, 43 in winter, and 17 in spring. In the same way Merian arranged all the earthquakes which had been observed in Basle up to the end of 1836, with the following results:

Summer 18.
Autumn 39.
Winter 41.
Spring 22.

The most important statistics of this character have however been furnished by Perrey of Dijon, who seems to have given special consideration to this subject. He has classified, according to the seasons of the year, 2,979 earthquakes, which have taken place in Europe and the immediately adjoining parts of Africa and Asia from the year 306 to the year 1844, and found:

653	to have taken place in	summer
705	"	autumn
911	"	winter
710	"	spring

The maximum falls in the coldest and the minimum in the warmest season of the year, while in spring and autumn the numbers are almost equal. Naumann considers that these observations almost conclusively prove that "at least in Europe and the countries immediately bordering on it, autumn and winter must "be regarded as the seasons in which earthquakes most frequently occur." He adds that it is difficult to find a satisfactory explanation of this fact, that the cause ought perhaps to be sought for more in cosmical than in meteorological relations, and finally asks "*May not the position of the earth in the winter, i.e. in the perihelion exercise an influence?*"* This question he leaves unanswered, contenting himself with declaring that the mere difference of temperature in the seasons of the year can not explain the matter. If, as is supposed in the first part of this paper, there exists in the interior of the crust a central metallic globe surrounded by a fluid zone, it is quite reasonable to suppose that the former may be influenced by the heavenly bodies, that it is attracted by the sun and moon, and that the attraction exerted is the more powerful the nearer these bodies approach the earth. Since the sun is nearest to the earth in the winter, there would appear to be grounds for attributing earthquakes partly to the attraction exercised

* Lehrbuch, I, 213.

by the sun upon the fluid interior, and the consequent pressure excercised by the latter on the earth's crust. It moreover appears from investigations made by Perrey subsequent to those above mentioned, that the moon also exercises an influence.*

Quenstedt† thus refers to the latter investigations: "A. Perrey "has found from 7000 observations during the first half of the "present century that earthquakes are much more frequent in the "conjunction and opposition of the moon than at other times; "more frequent, when the moon is near the earth than when it is "distant, more frequent in the hour of its passage through the "meridian than at any other. From this it would appear, that "the moon is not without influence; that it occasions tides in the "central lava in the same manner as in the ocean, which tides "press against the earth's crust and seek an outlet." The latter part of this quotation seems to contain the explanation least liable to objection, of the rise of the lava in volcanoes. Not only may plutonic and volcanic earthquakes be attributed to this cause, but volcanic eruptions also, and with equal justice. If we adopt this explanation it is easier to comprehend why the lava should press forth at one volcano in preference to another, or burst open the obstructed canals of extinct volcanoes rather than seek an outlet through the vents already existing in the earth's crust.

Having thus discussed the various explanations of the cause of the rise of the lava in volcanic canals, the phenomena which attend volcanic eruptions may next be adverted to, with the view of ascertaining the origin of certain volcanic products. The lava gradually ascending from the depths of the earth, comes in the upper part of the canal, and in the crater, into contact and conflict with the water which has found its way down from the surface, and which may have collected in subterranean reservoirs, or merely saturated the side walls of the vent. The water is by the heat of the lava resolved into steam, which then forces its way through the fluid to the surface, when the bubbles containing it explode. A similar phenomenon may be observed on a small scale at blast furnaces, when the slag runs out of the breast and over a place upon which water had been previously thrown. The slag boils up until it cools and becomes too stiff to allow of the passage of the steam. This production and escape of steam in the craters of volcanoes takes place with a violence and intensity of which few

* Bronn's Jahrbuch, 1855, 72

† Epochen der Natur, p. 812.

but eye witnesses can form any idea. Sartorius Von Waltershausen thus describes a volcanic eruption, principally in relation to the various products formed by it: "During an eruption the melted "matter ascends from the deeper lying regions of the earth into "the volcano, where it serves both for the formation of volcanic "ash and of lava. Steam prodigiously compressed tries, where it "can, to break through the column of lava to the atmosphere. "This escape of steam is the principal cause of that subterranean "noise known as volcanic thunder. A continual struggle takes "place between the elastic fluid, the fused mass and the solid "walls of the volcanic canal, which struggle lasts so long as the "development of steam in the latter continues. During this "violent ascent of the enormous steam bubbles, which burst on "reaching the surface of the lava reservoir, pieces of lava already "cooled, or still fluid, are violently torn off from the latter and "thrown high up in the air out of the crater. When the eruption "is at its height, millions of these pieces, mostly red hot, from the "size of mere miscroscopic particles to those with a diameter of "one or more yards, fill the air above the crater, rising in myriads "with each explosion, and falling again in perpetually changing "motion. When the intervals between each explosion are short, "as is the case with all violent eruptions, it frequently happens, "that during a lapse of about 20 seconds, which time the glowing "stones frequently take to complete their passage through the air, "six to ten new explosions take place. It is evident that an uninter'rupted volley and shower of stones mixed with the dense smoke of 'finer particles will thus be sustained, and this it is, which, partly "glowing itself, and partly lighted up by the glow of the melted lava, "in the crater, resembles a permanent flame. The fragments of "lava thus thrown out of the crater differ from each other in size, "in external form, (which is frequently determined by the tempe"rature at which they were formed,) and in chemical composition. "Blocks have been observed measuring 4 to 5 metres each way, "smaller ones about the size of a cubic yard occur frequently, "while from this size there are innumerable gradations down to "the finest dust. During an eruption, gravitation and the force "of the wind effect a separation of the fragments according to their "sizes. The largest of them fall back into or close around the "crater, the small pieces are thrown further, while the finer par"ticles are borne off by the wind and gradually deposited from it, "the coarser particles first, and ultimately the finest dust, which is

"often carried off several leagues from the volcano. This fine "dust is termed volcanic ash, and furnishes the principal material "for the formation of the layers of tuff which are so abundant in "volcanic districts. The fragments of lava possess at the moment "of their ejection from the crater very different temperatures. "Some of them, especially at the commencement of the eruption, "are scarcely warm, and possess the dark colour of scoriæ; others, "in greater quantity, are red and white hot—the latter remain for "a short time fluid and perfectly plastic, form themselves into "rotating ellipsoids, or adopt sometimes abnormal long-drawn "forms. These latter singular pieces have been termed volcanic "bombs. Decreasing in size, and becoming mixed with small "angular fragments, they graduate into what is called by "the Italians, lapilli, or volcanic sand." *

When the eruption has reached its climax, and the whole of the crater to a certain level has become filled with lava, the latter breaks out from beneath the dark crust that generally overlies it, at the lowest point of the bank of the crater, and rolls down the sides of the volcano, forming what appears as a stream of fire by night, and a thick viscid stream of slag by day. The lava leaves the crater red hot, and as fluid as melted metal, but shortly afterwards the stream cools and becomes solid on the surface, while it remains for a long time fluid in the inside, the heat there hidden showing itself here and there through the cracks in the solidified crust As the stream rolls on, these cracks close up, while others form at other places. "The whole surface is in continual motion; at "one point large bubbles are observed swelling up, which finally "burst and leave their rugged sides behind, standing erect in "the most curious forms; at another point cakes of slag in the "most varied positions are carried along, ploughing furrows as "they go, or tearing half-fluid lava with them and drawing it out "and winding it round in curious rope-like forms (the so called rope "lava). At some points the surface folds itself into deep cylin-"drical canals, which run on beside each other and parallel with "the direction of the stream; and at others, cross folds and depres-"sions are formed. Thus these lava streams present, in that part of "their course where this struggle between their fluid interior and "the solidified crust has taken place, an extraordinarily wild and "rugged appearance." †

* Die vulcanishe Gesteine in Sicilien nnd Island, p. 155.

† Naumann, Lehrbuch, I, 161.

According as a fused silicate cools more or less slowly, the structure of the resulting rock becomes more or less crystalline. No lava shows on its suface distinct mineralogical characters. Although traces of felspar or augite crystals make their appearance sometimes, they are nevertheless rendered unrecognizable by pieces of slag, the cavernous structure of the rock, atmospheric influences, etc. The non-crystalline character of the lava crust is of course attributable to its having been rapidly cooled. The great stream of 1669 from Etna, which is often 60 feet thick, is at several places in the neighbourhood of Catania intersected by quarries, in which the structure of its various parts may be studied. It is only at the depth of several feet, that the lava begins to be compact and homogeneous. It here consists of a light gray felspathic mass in which crystals of black augite and grains of green olivine are disseminated.* Many trachytic lavas of recent production possess distinctly crystalline characters containing in the compact mass crystals or grains of glassy felspar (sanidine).

From this sketch of various volcanic processes it would appear that there are being formed at the present day rocks entirely analogous to the basalts and trachytes, which have protruded themselves almost uninterruptedly through the earth's crust since the commencement of the tertiary period. We observe them solidifying from a condition as undoubtedly igneous as that of the slags which flow from our furnaces, and we observe them generally assuming the form of streams radiating from volcanic craters, or as layers on the more horizontal ground around these, which latter form of deposition forcibly reminds the observer of the basaltic layers of much earlier date and non-volcanic origin. Lava is not so frequently observed in the form of veins as are the earlier trachytes, nevertheless it is sometimes observed in this form on the sides of craters. The earlier eruptions of trachytic and basaltic rocks seem to have taken place through fissures in the earth's crust, somewhat in the same manner as the older eruptive rocks. The masses thus erupted assumed the form of isolated dome shaped hills or wide extended coverings, or even of whole stratified systems. In later periods we find these rocks gradually associating themselves with volcanic openings, and occurring in the form of lava streams, many of which are even traceable to the craters which emitted them. Fissures seem to have become more difficult of formation in the crust of the earth and in their place those

* Von Waltershausen: Gesteine in Sicilien und Island, p. 100.

canals of eruption seem to have been developed, which terminate on the surface of the earth in the craters of volcanoes. The transition from the earlier massive forms of deposition to the present peculiar volcanic type is so gradual and evident, that it is impossible to ascribe the former to any other cause than that from which the latter has been derived. Moreover it is impossible to discover any lithological difference between the trachytes of many lava streams, and other rocks of the same class, which occur constituting whole mountain masses.

It is further a very remarkable circumstance connected with basaltic intrusions that they have exerted upon the neighbouring strata effects which could only have been produced by great heat. These effects, such as the re-crystallization of limestone, the carbonizing of coal, etc., are too well known to require particularisation. Another fact which speaks for the igneous origin of basalts is the following:—In many basaltic veins their sides or selvages are composed of a crust of glass or slag, which gradually alters towards the centre of the vein into the granular rock. This circumstance is entirely analogous to that observed in many slags. These are often quite vitreous on the surface, where they have cooled quickly, while beneath they assume a granular and even crystalline texture.

In the first part of this paper I have referred to the chemical composition of certain rocks of the trachytic and basaltic groups. The analyses there given were however of the extremely siliceous trachytes and basic basalts. In Bischof's Chemical and Physical Geology there are recorded 27 analyses of trachytes, containing from 52 8 to 72·24 per cent. of silica, and averaging 62·91 per cent. In the same work there are given 22 analyses of dolerites and basalts, the content of which in silica ranges from 32·5 to 52·96 and averages 46·16 per cent. For the sake of completeness I insert here a list of the various species of the trachyte and basalt families, as given by Cotta, preparatory to adverting to certain peculiarities in the structure of some of them, which peculiarities will again be referred to towards the close of the present chapter in discussing the relation which exists betwixt granite and gneiss.

Massive Trachytic Rocks.

	Mineralogical constituents and principal characters.
Trachyte,	Sanidin (glassy felspar) and albite with hornblende or mica—granular.

* Cotta: Gesteinelehre, p. 78.

Trachytic porphyry,	Impalpable base with crystals of sanidine, &c.
Perlite,	Enamel-like mass; globular.
Obsidian and pumice stone,	Vitreous mass; impalpable to porous.
Phonolite,	Impalpable schistose base.
Andesite,	Friable mixture of albite, oligoclase, hornblende and magnetic iron ore.

*Tufaceous Trachytic Rocks.**

Trachytic breccia.
Trachytic conglomerate.
Trachytic tuff.
Phonolitic conglomerate.
Pumice stone tuff.
Trass.
Pumice-stone boulders.
Pumice-stone sand.
Alumstone.

Massive Basaltic Rocks.†

	Mineral constituents and general characters.
Dolerite,	Augite and labradorite; granular. phænero-crystalline.
Anamesite,	Augite and labradorite; constituents crypto-crystalline.
Basalt,	Augite and labradorite; impalpable, crypto-crystalline.
Nepheline-dolerite,	Augite and nepheline; granular to impalpable.
Leucite rock,	Augite and leucite; granular to impalpable.
Analcimite,	Augite, labrador, analcime; do.

Tufaceous Basaltic Rocks.‡

Basalt conglomerate.
Basalt tuff.
Peperino.
Palagonite tuff.

The rocks above mentioned belong to a class, the igneous origin of which is regarded by geologists generally, as controvert-

* Naumann: Geognosie, p. 709.
† Cotta; Gesteinlehre, p. 34.
‡ Naumann: Geognosie, I. p. 712.

ibly established. Nevertheless there are to be found among them instances of rocks possessing a characteristic hitherto almost exclusively ascribed to those of sedimentary origin. This is no other than the arrangement of some of the constituents of these rocks in a direction parallel to certain planes or lines. There exist numerous instances of undoubtedly igneous rocks possessing parallel structure as marked as that of many sedimentary rocks. Many trachytic porphyries possess this, especially those from the Island of Ponza and Palmarola, from the foot of the Oyamel in Mexico, and from the mountain Pagus near Smyrna.* Hoffmann also describes a trachyte from the Island of Pantellaria, between Sicily and Africa, which consists of a light greenish-grey compact fundamental mass, with crystals of sanidine and another mineral, which by their form, position and distribution occasion a marked schistose structure. Trachytes of this nature have been observed in the Island of Basiluzzo between Stromboli and Lipari, and in the Duchy of Nassau.† Slaty trachytes are also of frequent occurrence and have been observed by Leopold von Buch at Angostura and near Perexil in Teneriffe, and in the Canary Islands at the Caldera of Tiraxana and at Mogan on Grancanaria. Also by Burat in Velay, especially at St. Pierre Eynac, at the Pas-de-Compain and in the Mont Dore.‡ The slaty trachytes described by Burat are classed by other geologists among the phonolites, which latter also furnish most remarkable instances of parallel structure among igneous rocks. Phonolites as a class possess this slaty structure, which is caused by the parallel position of the tabular-looking crystals of felspar contained in it, and on this account the rock can often be split up into slates and flags. This slaty structure stands also in connection with the form in which these rocks have been deposited. In phonolitic mountains it is generally observed that the flags, and the layer-like subdivisions of the rock corresponding to them are arranged around the axis of the mountain in a bell shaped system of strata, the inclination of the latter decreasing as the summit of the mountain is approached. This would seem to indicate that the parallel structure was occasioned by the flow of the phonolitic material from the opening in the summit over and down the sides of the mountain. This view is further supported by the fact that many lavas possess a marked linear parallel structure, sometimes com-

* Lehrbuch, I, 632.
† Lehrbuch, I, 634.
‡ Lehrbuch, I, 635.

bined with an evident distension of their crystalline constituents in a direction parallel with the course of the lava stream. According to Spallanzani and Dolomieu this phenomenon is of great importance, since it was doubtless occasioned by the moving forward and the extension of the half-fluid lava, an explanation amply confirmed by the elongation in the direction of the stream of the cavities filled with gas which are contained in the lava. In the Leucite-lava of Borghetto the crystals of leucite in spite of their tesseral form are even drawn out in the direction of the stream.* These instances of parallel structure among the trachytic and basaltic rocks have been specially dwelt upon, because of the analogy they present to gneiss and other schistose rocks of the primitive gneiss formation.

Porphyry, Greenstone, and Melaphyr.—It has been already mentioned, that the trachytic and basaltic rocks first make their appearance about the commencement of the tertiary period. Instances of such rocks occur however even earlier, in the trias formation, in passing backward through which we find that their character gradually changes. Porphyries result on the one hand, and melaphyrs, or commonly called traps, result on the other. The rocks usually comprehended under the name melaphyr are, according to Cotta, of a very indefinite character, and resolvable partly into basalt, partly into greenstones, and partly into porphyrites (porphyries free from quartz). On this account it would appear advisable to classify most of the eruptive rocks, which have been protruded during the Silurian, Carboniferous and Permian periods into two great divisions, viz: porphyries and greenstones. With regard to the igneous origin of these, I cannot do better than quote the argument of Naumann.† "We "have seen, that if the rocks of the lava family (as no one doubts) "must be regarded as pyrogenous formations, then the rocks of "the basalt and trachyte families have a similar origin. If now "the melaphyrs (or traps) are compared with the basalts, and "the felsitic porphyries with the trachytic porphyries, an aston-"ishing similarity will be observed to exist between them; a "similarity which renders it often quite impossible to distinguish "the one from the other, when hand-specimens of them merely "are examined. According to Bergmann and Delesse, we may "recognize the same mineralogical constituents in melaphyr as in

* Lehrbuch, I, 468.
† Lehrbuch, I, 737.

" dolerite, anamesite, and basalt. It shows quite similar amyg-
" daloidal forms to those of the latter rocks. It is a massive
" rock, sometimes with columnar development, a completely non-
" fossiliferous rock like basalt. All these coincidences, from a
" lithological point of view alone, appear completely to justify the
" view that the melaphyrs, like the basalts, must be numbered
" among pyrogenous rocks. In the felsite-porphyries, it is true that
" common orthoclase takes the place of the glassy felspar of the
" trachytes, still the difference between these two minerals must
" be looked upon as trifling, especially when it is remembered, that
" most orthoclases contain some soda besides the potash. More-
" over, the remaining constituents, albite, oligoclase, mica, and
" quartz are common to the trachytic-porphyries and to the
" andesites, as well as to the felsitic-porphyries, while the labra-
" dorite brings certain porphyrites in very close relationship to the
" melaphyrs, from which they are sometimes almost undistinguish-
" able. The unprejudiced enquirer will therefore surely without
" hesitation regard the felsitic porphyries as rocks quite analo-
" gous to the trachytic porphyries, with which they also
" correspond in many other properties. There are also other
" rocks, regarding the origin of which we must come to similar
" conclusions. The diabases consist essentially of oligoclase or
" labradorite and pyroxene; the diorites of albite, hornblende,
" and quartz; both classes therefore of exactly the same minerals
" as we observe occurring in lavas, basalts and trachytes. In
" mineralogical and chemical respects therefore, no objection can
" be taken to the supposition that they have been formed in a
" manner exactly similar to these latter rocks. When we add to
" this that these greenstones are always completely non-fossiliferous,
" generally massive and supplied with structures and forms of
" deposition quite similar to those of the basalts and lavas, the
" above supposition would appear to be in every respect justifi-
" able." With regard to the chemical composition of these rocks we find, that if we take the analysis of three hornblendic porphyries, and of a similar number of felsitic porphyries, as given in Bischoff's Chemical and Physical Geology, the contents of silica of these ranges from 77.9 to 59.87, and averages 67.77 per cent. If we further take the analysis of greenstones and melaphyres contained in the same work, we find their percentage of silica to range from 55.29 to 42.72, and average 50.9.

The porphyries seem to have been formed principally during the Carboniferous and Permian periods. They often occur in the

midst of granites and syenites, in which they form veins, so that they are generally newer than these latter rocks. A few of them are decidedly older than the coal period, and several have been formed simultaneously with the Bundtsandstein of the Triassic, and even in the Jurassic and the chalk formations, but the height of their development falls in the Carboniferous and the first part of the Permian period, in the German Rothliegendes. In the latter formation the porphyries have played a very important part, furnishing the material for many of its sedimentary rocks, and dislocating its strata considerably by their intrusion. In the carboniferous system porphyries break through and materially disturb the strata, forming veins or dykes, and inserting themselves horizontally as layers. While, as we have already mentioned, the basalts and trachytes exert a powerful chemical action on the rocks with which they come in contact, the influence of the porphyries seems to have been almost exclusively of a mechanical nature. It seems as if the porphyritic material on its arrival in the upper parts of the earth's crust did not possess such a high temperature or such a great degree of fluidity as the basalts. On the other hand, the rocks broken through by the porphyries, show evidence of the enormous violence to which they have been subjected, huge pieces having been broken off, surrounded by the porphyritic material, carried off by it, and crushed and pulverized in its further progress. In this way have been formed the numerous breccias which occur in veins and masses of porphyry, where they adjoin the side rocks. Sometimes the mechanical action has been so violent as to produce even a more finely divided material, which in the form of a sandstone-like or clay-like substance constitutes the selvages of many porphyritic veins. By far the most conclusive proofs however of the enormous forces which were at work during the eruption of the porphyry, are to be found in the dislocations which whole systems of strata have undergone. The neighbouring beds have been raised up, folded and fractured, while friction-grooves, and surfaces worn smooth by the sliding of one mass upon another occur at the junction of the erupted rock with the neighbouring strata. These effects furnish almost as conclusive evidence of the igneous origin of the porphyries as the chemical changes on the adjacent rocks do, as to the igneous origin of basalt.

With regard to the greenstones, they seem to have made their appearance in very great profusion during the Silurian and Devon-

ian periods, and even earlier, although in lesser quantity among the primitive slates. In the Carboniferous system, they are intruded almost as frequently as the porphyries; but towards the commencement of the Permian period, they seem to be replaced by melaphyres, which continue to be erupted even as late as the Triassic period. The circumstances attending the protrusion of the greenstones and melaphyres are essentially the same as in the case of the porphyries. The strata which the former have broken through furnish abundant evidence of the extraordinary force which ejected them, and the dislocated strata also occasionally furnish proofs that they have been chemically acted on by the plutonic rock. This latter is especially the case with the melaphyres, which have frequently carbonized the coal and hardened the clay slates with which they have come in contact, in the same manner as more recent eruptive rocks. In the following tables will be found the names and characters of the rocks referred to in this paragraph.

*Massive rocks of the Porphyry class.**

NAME.	CRYSTALS OCCURRING IN THE PASTE.	CHARACTER OF THE PASTE.
Quartz porphyry.	Quartz and Feldspar.	Yellow, brown and red colored.
Syenitic porphyry.	Quartz, Chlorite Feldspar, sometimes Mica.	Brown or green; somewhat granular.
Granitic porphyry.	Quartz, Mica, Feldspar.	Sometimes granular.
Micaceous porphyry.	Mica and Felspar.	Brown coloured.
Minette.	Mica and Felspar.	
Hornblendic porphyry.	Hornblende & Feldspar.	Dark coloured.
Felspathic porphyry.	Feldspar.	
Felsite rock.	Sometimes Quartz.	Yellowish, reddish, or greenish-grey.
Pitchstone, and Pitchstone porphyry.	Glassy Feldspar, Quartz and balls of Felsite.	

Rocks made up of Porphyritic debris.†

Porphyry breccia.
Porphyry conglomerate.
Porphyry sandstone (psammite.)
Porphyritic tuff or felsite tuff. Claystone.

Massive rocks of the Greenstone and Melaphyre class.‡

NAME.	ESSENTIAL CONSTITUENTS.	TEXTURE.
Diabase.	Augite, Labradorite, and Oligoclase.	Granular, porphyritic and slaty.

* Cotta, Gesteinslehre, p. 97.
† Naumann, Lehrbuch, I, 706.
‡ Cotta, Gesteinslehre, p. 47.

NAME.	ESSENTIAL CONSTITUENTS.	TEXTURE.
Calcareous Diabase.	Augite, Labradorite or Oligoclase & Calcite.	Granular, impalpable, slaty, concretionary.
Gabbro.	Diallage or Sm·ag-dite with Laorado-rite and Saussürite.	Granular, slaty and concretionary.
Hypersthenite.	Hypersthene and Labradorite.	Granular.
Augite-rock.	Augite.	Granular to impalpable.
Norite.	Hornblende and Felds-par, Hypersthene and Feldspar.	Granular.
Diorite.	Hornblende and Albite.	Granular, slaty.
Globular Diorite.	Hornblende and Anorthite.	Granular and globular,
Micaceous do.	Hornblende, Oligoclase, Orthoclase and Mica.	Granular.
Hornblende rock.	Hornblende.	Granular or impalpable.
Hornblende-slate.	Hornblende.	Slaty.
Actinolite slate.	Actinolite.	Slaty.
Kersanton.	Hornblende and Mica.	Granular.
Eclogite.	Smaragdite and Garnet.	Granular, slaty.
Disthene rock.	Disthene with Garnet and Mica.	Granular, slaty.
Aphanite.	Feldspar and Pyroxene or Amphibole.	Impalpable, porphyri-tic, slaty, cellular, amygdaloidal.
Serpentine.	Serpentine.	Impalpable, porphyri-tic slaty.
Schiller rock.	Schillerspar and Ser-pentine.	Granular.
Garnet rock.	Garnet, Hornblende, and Magnetite.	Granular.
Eulysite.	Garnet, Pyroxene, and iron oxide.	Granular, impalpable.
Epidosite.	Pistazite and Quartz.	Granular, impalpable concretionary.
Labrador rock.	Labradorite and Hornblende.	Granular, porphyritic.

*Fragmentary rocks of the Greenstone and Melaphyre class.**

Greenstone conglomerate and greenstone breccia.
Greenstone sandstone (psammite.)
Greenstone tuff.
Schalstone.

It will be observed from the foregoing tables, that by the action of water on the porphyries and greenstones rocks have

* Naumann, Lehrbuch, I, 703.

been formed similar to the conglomerates and tuffs of the volcanic formations, and probably in a similar manner. Moreover just as in these formations we find among the massive rocks above enumerated many instances of undoubtedly igneous rocks possessing a slaty structure. Many feldsitic porphyries possess a streaked texture caused sometimes by bands of varying colour, and oftener by the arrangement of the quartz grains or crystals in parallel layers, or the presence of thin laminæ of quartz in the paste.* The instances of a similar modification of structure among the greenstones are very numerous, and they are even more important as showing more clearly the cause of this structure among igneous rocks. The diorites usually occur in the form of veins, irregular masses (typhonische Stöcke,) and layers. The veins sometimes exhibit the following remarkable phenomena. In the middle they consist of granular diorite, and at the sides of slaty diorite or hornblende slate, a gradual transition being generally observable from the granular to the stratified rock. Somewhat similar instances of this nature have already been referred to in the paragraph concerning the basaltic rocks. The cause o these phenomena may most reasonably be sought for in the circumstances attending the cooling of the rock, and they are most likely the same as those which occasioned a similar structure among the porphyries. The fluid rock of the diorite vein was probably in motion in the centre, while the parts adjoining the side walls were solidified. The current in the centre would have a distending and arranging action at the junction of the fluid with the solidified parts, and an elongation and parallel grouping of the minerals there being formed would be the consequence. Not only has this slaty texture been observed in connection with veins, but it has also been remarked, that the more irregular masses of diorite assume a slaty structure towards their junction with the other rocks, the stratification being, as in the case of the veins, parallel with the line of such junction. Naumann adduces numerous instances of this sort;† and from a former paper of mine it will be observed, that they often occur in Norway.‡ Among the melaphyrs or traps the same circumstance is often remarked. In the melaphyr region south of the Hundsrück this rock, when it occurs in veins, often possesses a degree of parallel structure sufficient to cause it to separate into flags, which

* Lehrbuch, I, 616.

† Lehrbuch, II, 403.

‡ Canadian Naturalist, VII, 115.

lie parallel with the walls of the vein. The trap of Kerrera decribed by Macculloch is another instance of slaty texture in trap veins. In this case the rock constituting the sides of the vein is filled with scales of mica, which all lie parallel to the enclosing walls. The same author also remaks concerning the hypersthenite of Sky, that the crystals of hypersthene "are laminar and "placed in a position parallel to each other, and as in gneiss to the "plane of the bed in which they lie." Another peculiarity, which shews the influence of igneous flow on the structure of a rock is the following: The amygdaloidal varieties of melaphyr sometimes possess an arrangement of their cavities corresponding to that possessed by the gas bubbles of lavas. They are often elongated,in which case their longest axes lie parallel to each other, and we may suppose as in the case of lava, to the direction of the flow of the igneous material.

Granite and Syenite.—These formations include the oldest eruptive rocks, the granites and gneiss-granites, which during the primitive period seem to have broken through the comparatively thin crust of the earth then existing. Later granitic eruptions seem to have taken place with great frequency throughout the Silurian, Devonian and Carboniferous periods, after which they gradually disappear. Syenite does not seem to appear in the Primitive Gneiss formation until long after the first general dislocation of the same and the protrusion of the granite had taken place. The principal syenitic eruptions seem to have occurred during or shortly after the deposition of the Silurian and Devonian rocks, although there are many instances of much younger syenites. The rocks appear after their protrusion to have assumed all the forms of occurrence, which we are accustomed to observe in plutonic and even volcanic formations; irregular masses, covers, (nappes), layers and veins; every form except the stream of the volcanic rock. But it is to be remarked that instead of veins or dykes being the most common form, as in the newer plutonic formations, the irregular masses preponderate. These masses are not to be confounded with the covers or cap rocks of the basalt and trachyte formations. They are huge islands of granite as it were, possessing generally an elliptical shape, and occurring in the midst of stratified rocks, which are sometimes vertical, and which often lean against the granite as if it were the immediate cause of their inclined position. One of the most important phenomena observable with regard to granite in all its forms of occurrence is the extent to

which it contains huge masses and smaller fragments of other rocks. This is one of the most conclusive proofs of the power of the forces at work during the protrusion of the granite, and taken in connection with its forms of deposition furnishes incontrovertible evidence of its eruptive origin. Among the objections which have been made to this view, the most important is that founded on the circumstance that the quartz of granite has been the last of its constituents to solidify. Many theories have been proposed to account for this circumstance but it would seem necessary before attempting its explanation to enquire whether this alleged behavior of the quartz is really the fact. It is doubted by a few geologists, and altogether denied by Sartorius von Waltershausen, who remarks that according to his experience in the primary rocks especially in granite as well as in the volcanic rocks, quartz corundum and periclase have always first been separated. "For instance," he says, "I have minutely examined the granites from "Baveno, from various districts of the Grimsel, from Mont Blanc, "from the Oker valley (Harz), from the Island of Mull and many "other places, and those rocks show that the quartz solidified "first, then the mica and finally the feldspar."* In the face of such a distinct statement it might not be safe to regard as thoroughly established the fact whereon the above objection to the eruptive origin of granite is founded.

With regard to the chemical composition of granite, its content in silica, according to 18 analyses mentioned by Bischof, ranges from 63.3 to 76.02 per cent., and averages 69.33 per cent. Only two analyses of syenite are on record, the silica being estimated as 61.72 and 66.39 per cent.; average 64.05. If we compare these figures with the average content in silica of other eruptive rocks we find generally a diminution in the quantity of silica as the rocks become more and more recent, provided always that their classification into two great series of siliceous and more basic rocks is kept in sihgt. Thus the acid series comprehend:

Granites	69.33	per cent. of silica.
Porphyries	67.77	" "
Trachytes	62.91	" "

The basic series on the other hand consist of:

Syenites	64.04	per cent. silica.
Greenstone and Melaphyrs	50.65	" "
Dolerites and Melaphyrs	46.16	" "

* Die Vulcanische Gesteine, &c., p. 225.

Bunsen and Streng are inclined to extend the theory of the normal trachytic and basaltic magmas, mentioned in the first part of this paper, so as to include the plutonic rocks, and to maintain that granites, porphyries and the older eruptive rocks are capable of being also regarded as mixtures of the two hypothetical melted masses. Of course the same objections which apply to this theory so far as basaltic and trachytic rocks are concerned, apply also in the case of the older rocks. On the other hand von Waltershausen's theory, also previously described, furnishes a complete explanation of the cause of the more siliceous character of the older rocks. The same increase of density and of basic constituents, which he supposes now to take place from the surface to the centre of the earth, existed in the oldest geological periods. The fused material, which, on breaking through the earth's crust solidified to granite, was the uppermost concentric layer then existing. It was lightest in weight and richest in silica. Beneath it lay successive layers graduating into each other, and with the depth increasing in density and basic constituents. But according to this theory, the magmas from which granites, porphyries, and trachytes resulted ought to have had a position nearer the surface than the fused matter which on its eruption yielded syenites, greenstones, melaphyres, and basalts. Hence the former rocks ought to have been the first to appear upon the earth's surface. Porphyries ought to have preceded syenites, and trachytes ought to have broken through the earth's crust and solidified prior not only to basalt but to greenstone and melaphyre. This is, however, not the case, and Sartorius von Waltershausen fully appreciates the difficulty, mentioning that the trachyte of Esia near Reikjavik, "which according to its mineralogical character 'belongs to a higher-lying zone nevertheless intersects in the 'form of a vein the strata of Iclandic trap, which in general "originate from deeper regions."* To explain the difficulty he resorts to the theory "that the earth's crust possesses different "thicknesses in different places, or that the surface of separation "between the already solidified and the still fluid masses represent, "a relief turned inwards, of mountains and valleys. Now where "such a mountain accidentally reaches down into greater depths, "melted masses might be able, through fissures in it, prematurely, "to escape to the surface, which masses might be broken through "later by rocks of higher zones which had remained longer fluid.

* Die Vulkanische Gesteine, etc. p. 337.

"The anomalies in the Esia trachyte formation might perhaps "also be explained by movements of the fluid matter in the "interior, or by alterations in the relief forms of the surface of "separation just mentioned." The method of explaining these anomalies by movements in the fluid matter existing beneath the crust would appear to be the most reasonable, and I shall endeavour as briefly as possible to refer to it more minutely.

We have already seen in referring to the cause of earthquakes and volcanic eruptions, that it is not impossible that movements take place in the interior of the earth similar to tides in the ocean on its surface. We shall suppose the two lines within the dark coloured crust in the subjoined figure (1) to represent respectively

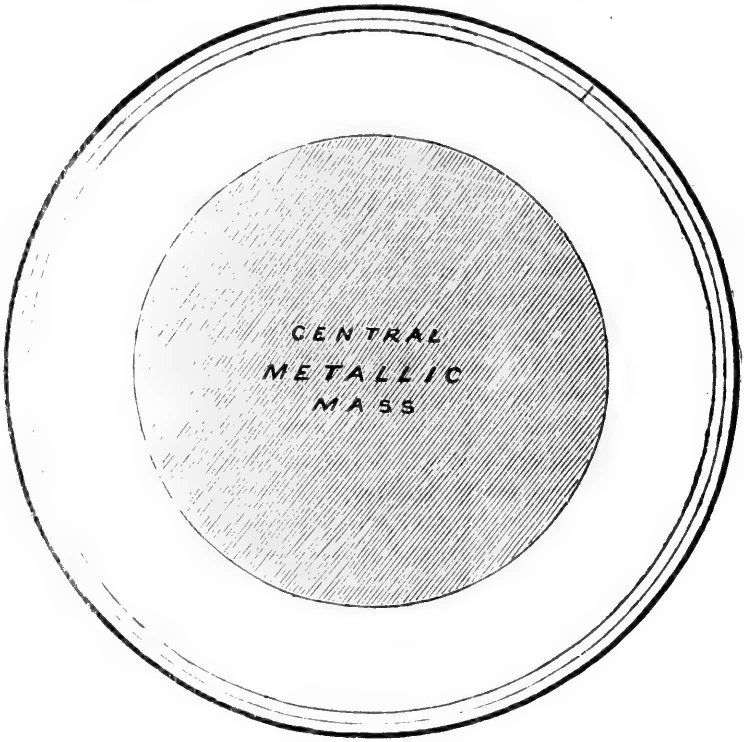


Fig. 1.

the normal limits towards the interior of the acid, and the more basic melted matter, which in the earliest periods as now, may be supposed to have graduated into each other and yielded all the varieties of eruptive rocks now visible on the surface. We shall

suppose further that a change comparatively slight takes place in the position of the metallic centre. It is evident that the consequence of this would be to press the higher zone against the solidified crust, and further to each side, bringing the lower zone in contact with the crust at *a*, as shown in figure 2. If at this

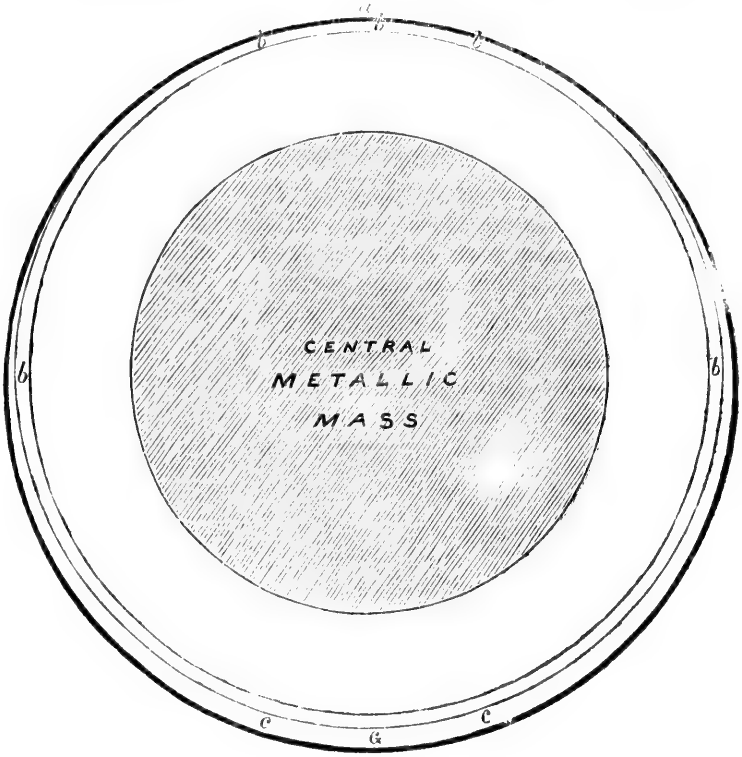


Fig. 2.

part of the crust there existed fissures or volcanoes, the denser *and more basic mass, b* would be erupted, while the acid mass, *c* would remain in the interior. As soon, however, as the central mass resumed its normal position the conditions would be re-established for the protrusion of the more acid rock of the superior zone. In this way the alternate eruptions of highly silicified matter and then of extremely basic rock with all the innumerable gradations that exist between them, would seem to be capable of explanation. The amount of divergence of the metallic mass from the centre necessary to produce the effect

above described is so inconsiderable, that it does not appear unreasonable to attribute to the heavenly bodies the power of causing it. Still it would be very desirable if mathematicians would devote some attention to the subject.

The rocks of the granite family have been arranged by Cotta* according to their granular and slaty varieties, as follows:

ESSENTIAL CONSTITUENTS.	RESULTING ROCKS.	
	GRANULAR.	SLATY.
Feldspar and Hornblende.	Syenite.	Slaty Syenite.
Feldspar, Quartz, Mica and Hornblende.	Granitic Syenite.	Syenitic Gneiss.
Feldspar, Quartz and Mica.	Granite.	Gneiss.
Feldspar, Quartz and Talc.	Protogine.	Protogine Gneiss.
Feldspar, Quartz and Chlorite.	Chloritic Granite.	Chloritic Gneiss.
Feldspar, Quartz and Graphite.	Graphitic Granite.	Graphitic Gneiss.
Feldspar, Quartz and Iron Mica.	Iron Granite.	Iron Gneiss.
Feldspar, Dichroite and Mica.	Dichroite Granite.	Dichroite Gneiss.
Dichroite, Mica and Garnet.	Dichroite Rock.	not known.
Feldspar, Elæolite and Mica.	Miascite.	not known.
Feldspar, Quartz and Schorl.	Schorl Granite.	not known.
Quartz, Schorl and Topaz.	Topaz rock.	
Oligoclase and Mica.	Kersantite.	Kersantite.
Feldspar and Quartz.	Granulite.	Granulite.
Quartz and Mica.	Greisen.	Mica slate.

The sedimentary rocks of the granite family are as follows:†

Granitic conglomerate.
Syenitic do.
Gneiss breccia and gneiss conglomerate.
Arkose (Feldspathic sandstone).

These latter rocks, however, bear but little analogy to the tufaceous rocks of later eruptive formations. Instead of being formed and deposited simultaneously with their corresponding massive rocks, they have generally been derived from the abrasion of these, long after their eruption and solidification, and deposited with the rocks of comparatively recent sedimentary formations. There do not seem to exist or have been formed with granitic eruptions any rocks of a tufaceous character. The obvious inference to be drawn from this circumstance is, that during at least the older granitic eruptions no water or ocean existed on the earth,

* Gestein slehre, p. 114.

† Lehrbuch, I, 702.

from the conflict of which with the fluid granite such rocks could result. At the time of these eruptions, therefore, the temperature of the earth's surface must have been higher than the boiling point of water, and the whole of the latter now condensed on the surface must then have existed only in the atmosphere.

With regard to the stratified varieties of granitic rocks it will be seen from the above table, that such have been abundantly developed. Even syenites occasionally possess parallel structure, as is the case of those of the Plauensche Grund near Dresden, of Ullern-Aasen, near Christiania, and of the Odenwald. A banded structure has been observed in the syenites of Brotterode in Thuringia, of Jurgojaskaja in Asiatic Russia, and of the Malvern Hills. Phillips regards this structure, in the latter instance, as having been produced during the original solidification of the rock.* He remarks that "the laminar and banded structures may be regarded as indications of crystallization under restraint, such restraint having reference to particular planes in consequence of the pressure of preconsolidated parts adjacent." One of the most important transitions observable among these rocks, however, is the stratification of granite, whereby it gradually assumes the character of gneiss. The most abundant and striking examples of this are to be found in the Primitive Gneiss formation, where granite occurs in beds between gneiss strata, and forms gradual but distinct transitions into these, by the laminæ of mica gradually arranging themselves parallel to each other, and parallel to the direction of the strata generally. But the irregular masses of granite to which we have already referred have also often been observed to assume a slaty structure as they approach the rocks adjoining them. One of the most remarkable examples of this occurs in the Primitive Slate formation of Upper Tellemarken in Norway, especially in the neighbourhood of Aamdal, Vraadal, Hvideseid, &c. In the interior parts of the granitic protrusion, the rock is thoroughly crystalline. Towards its limits, gneissoid granite is developed, the foliation of which is invariably parallel with the line of its junction with the adjoining rocks. That the rock here referred to is decidedly eruptive is proved by the numerous fragments of neighbouring slate enclosed in it.† Instances of exactly the same phenomenon have been observed near Taubenheim, in Saxony, and in the valley of the Schwarza, in Thuringia. At the latter place the granite is

* Mem. of the Geol. Survey of Great Britain, II. 1, p. 74.

† Dahll: Om Thelemarkens Geologie, p. 7.

in the form of a long drawn mass, in the centre of which it is distinct and characteristic, while towards the hanging wall it graduates into gneissoid rock. The central granite or protogine of the Alps, according to Delesse, also graduates at its limits into gneiss, and this, according to Raymond and Charpentier, is the case with the colossal granite masses of the Pyrenees. These various instances furnish good grounds for maintaining that gneiss bears the same relation to granite, that diorite slate or hornblende slate bears to many granular diorites, the micaceous selvage of the Kerrera trap vein to its granular centre, and the numerous instances of stratified or banded porphyrites or trachytes, to the corresponding granular rocks. In short there would appear to be reason for assuming that gneiss is as much an igneous rock, as are the banded or stratified varieties of igneous rocks just mentioned. The instances just given prove at least that certain gneisses are eruptive, because they are nothing else than an outward covering, a contact modification of the eruptive granitic masses. There are, moreover, instances on record of gneisses occurring in veins, and sometimes enclosing fragments of other rocks. Humboldt mentions an instance occurring near Antimano, in Venezuela, where mica slate is intersected by veins from thirty-six to forty-eight feet thick, and consisting of gneiss filled with large crystals of feldspar; and Fournet maintains that in the mountains of Izeron, true eruptive gneisses occur in veins intersecting other gneissoid rocks.* Darwin relates that the granitoid gneiss of Bahia contains angular fragments of a hornblende rock, and that a similar gneiss occurring in Botofogo Bay, near Rio Janeiro, contains an angular piece seven yards long and two broad, of a very micaceous gneiss.† Instances of the same nature have been observed by Naumann near Ullensvang in Norway and by Boethlingk near Helsingfors in Finland.‡ The most satisfactory explanation which can be given of the formation of the gneissoid selvage to granitic masses is that which is given by Phillips in the case of syenite, and already quoted. It is a consequence of crystallization under restraint or pressure, accompanied by a movement of the solidifying mass somewhat in the same manner as indicated in the case of greenstone. Naumann adopts almost the same explanation in referring to the formation of igneous

* Naumann, Lehrbuch, II, 180.

† Geological Observations on South America, p. 141.

‡ Lehrbuch, II, 113.

strata. His remarks on this point are as follows: "Let us imagine that an igneous mass crystallizing as it slowly cools, is confined between two parallel planes, which exert both pressure and resistance; the cooling, and consequently the solidification will commence at and proceed from these enclosing planes. Now, if in the solidifying mass the conditions exist for the development of many lamellar bodies (such as crystals of mica) then each of those bodies will, in consequence of the pressure, assume a position parallel with the enclosing surface, and the rock will be furnished with a plane parallel structure more or less distinct. If, further, the process of solidification does not progress regularly, but with periodic interruptions, then the rock would be divided into layers lying parallel to the enclosing planes. If the whole mass, during the progress of the solidification was in regular motion up and down then there would be developed in each a linear parallel structure or distension of the rock more or less distinct." * Whether the parallel structure of the gneiss of the Primitive formation may be attributed to causes similar to those here indicated, is a question reserved for consideration in the third part of this paper. Meanwhile it may be remarked that the granite occurring in beds in that formation, between the zones or layers of gneiss is so intimatey, connected with the latter rock by lithological transitions that it would seem to be altogether inseparable from it, and that the same origin attributed to the one must belong to the other. In the gneiss-granite of the mountains of Lower Silesia, the granular and slaty modifications of that rock are, according to Von Raumer, regularly interstratified with each other. In Podolia, according to Von Blöde, granite and gneiss together form a whole, to which a contemporaneous and similar mode of formation is ascribable. In Scandinavia and Finland, in the central plateau of France, in Scotland, in Brazil, and Hungary the same relations betwixt granite and gneiss exist. "En Hongrie,"† says Beudant, "ces deux roches se montrent toujours ensemble et uniquement ensemble, elles ne forment pas des couches alternatives, mais une seule et même masse." If, therefore, granite, as we have seen, is undoubtedly igneous, then the primary gneiss must be of the same origin, and in this manner we obtain a proof of the original state of the igneous fluidity of our globe. Gneiss is the oldest formation, and if it can be reasonably shown to be igneous, then it must have

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Lehrbuch, I, 496.

Voyage en Hongrie, III, p. 19.

been the rock first solidified; and previous to this, it, as well as all subsequent eruptive formations, and the material of all sedimentary rocks must have been in a state of igneous fusion. The theory of the igneous state of the original globe is, however, probably so well established as to require no further proof. It is an axiom without which it is impossible satisfactorily to account for the phenomena of volcanoes and hot springs, the elevation of mountains, the increase of temperature on penetrating into the earth, the phenomena of terrestrial magnetism, the formation of crystalline rocks, and the flattening of the earth at the poles. In the third and concluding part of this paper I shall advert more fully to this hypothesis, of the conditions which must have co-existed with the earth's original fluid state.

III. The Primary Formation.

Following out the plan indicated in the first part of this paper, we proceed to the consideration of the primary rocks, with the view of ascertaining whether they, in part at least, may reasonably be regarded as constituting the first solidified crust of the earth. The igneous condition of the original globe has already been adverted to, and it would seem unnecessary here to refer at length to what may be called the keystone of this theory, viz. the flattening of the earth at the poles. It is sufficient to remark on this point, that Newton and Huygens first maintained and proved this to be the case, from mathematical grounds alone. Subsequently numerous measurements of the length of a degree in various lands, but especially in those near the equator and under the polar circle, have thoroughly established the truth of Newton's theory. They have proved that the length of a degree of latitude increases with the distance from the equator. The following are some of the results obtained:

	Latitude.	Length of degree of Latitude.
Peru	1°31	56736.8 toises.
India	12°32	56762.3 "
France	46°8	57024.6 "
England	52°2	57066.1 "
Lapland	62°20	57196.2 " *

The meridian lines are therefore more considerably curved in the neighbourhood of the equator than at the poles, and the equatorial diameter of the earth is consequently greater by about 24 geographical miles than the polar diameter. This is of course, a

* Muller's Kosmische Physik, p. 51.

consequence of the revolution of the earth on its axis, and of the influence of centrifugal force. This influence could not, however, have made itself felt, had not the earth been originally in a fluid, or at least plastic condition, so that the depression at the poles constitutes one of the most unequivocal proofs of the original fluid condition of the globe.

Assuming this fluid condition to have been owing to the prevalence of an extremely high temperature, we are necessitated to suppose that the atmosphere was then very differently constituted than it is at present. This has been remarked by many previous writers. Dr. Hunt describes it as "an atmosphere holding in the state of acid gases all the carbon, the sulphur and the chlorine, besides the elements of air and water."* Quensted remarks: "According to the igneous theory the whole of the siliceous rocks were originally in lava-like fusion. It follows of course that not only the whole of the sea must have existed in the atmosphere. but also a multitude of substances, which could not exist otherwise than in the gaseous state, such as carbonic acid, chlorine, sulphur, etc."† These inferences are legitimately drawn. The sandstones, shales, and the fixed parts of the limestones of sedimentary formations then existed in the fused matter, along with the materials of the igneous and primary rocks, the soda of sea-salt and the inorganic constituents of plants and animals. On the other hand, the carbonic acid of the limestones must have existed in the atmosphere. The chlorine of the sea salt also could scarcely have existed anywhere else than in the atmosphere in combination with hydrogen, or with those metals which form with it volatile chlorides, such as lead, zinc, copper, iron, cobalt, nickel, etc. Those volatile chlorides, which are decomposable while in the gaseous state by oxygen, (such as those of the three metals last named) could not however have existed in an atmosphere containing free oxygen, but it would seem, that the primitive atmosphere did not contain any such free oxygen. Bischof first adopted this view. He maintains that the carbon disseminated through the dark clay slates of the pre-carboniferous periods, is in itself more than sufficient to take up all the oxygen which the atmosphere of the present day contains.‡ He calculates also that a stratum of carbon, spread over the whole surface of the globe, 2.6 feet thick, would be sufficient to convert all the

* Canadian Naturalist, p. 202.

† Epochen der Natur. p. 20.

‡ Chem. and Phys. Geologie, ii. p. 35.

oxygen of the atmosphere into carbonic acid; and after considering how richly furnished the sea is with animal and vegetable life, how rich its sedimentary deposits must be in organic substances; that the earlier sedimentary rocks are highly changed with carbonaceous and bituminous substances, that beds of coal and lignite are spread over an area of many hundreds of square miles with a very considerable average thickness, he comes to the conclusion, that a layer 2.6 feet thick is far from being an equivalent to all the carbon existing in the earth, leaving altogether out of the question the carbon of the organic world on its surface. This opinion certainly seems to be well grounded, and there would appear to be just reason for supposing that the oxygen of the atmosphere existed originally in the state of carbonic acid, and that a considerable quantity of carbon, besides that which was in combination with the oxygen, must have existed in the original atmosphere, either free, or in combination with other elements, and probably especially with hydrogen. Thus the gaseous envelope of the original globe must have been an enormous atmosphere of water, carbonic acid, carburetted hydrogen, and nitrogen, together with comparatively small quantities of sulphurous acid, and sulphuretted hydrogen, hydrochloric acid and metallic chlorides. The pressure of such an atmosphere must have been prodigious, at least 100 times greater than that of the present time; and in conjunction with its composition sufficient to produce effects totally different from those caused by atmospheric influences at the present day. Among its most remarkable properties must have been its power of absorbing heat. Dr. Hunt has shown that the atmosphere of paleozoic times must, from the amount of carbonic acid in it, have greatly aided to produce the elevated temperature then existing.* How much more must this have been the case when the atmosphere contained such hydro carbons as marsh and olefiant gases, whose power of absorbing radiant heat greatly exceeds that of carbonic acid.† Dr. Hunt has indeed indicated the part which such hydrocarbons may thus have played. After the fluid globe had sufficently cooled, to allow the condensation of some of the constituents of this primitive atmosphere, the action of these on the earth's crust must have been very energetic, and must have caused the formation of products differing considerably from the sedimentary deposits of

* Canadian Naturalist, vol. viii. p. 324.

† Tyndal: Heat considered as a mode of motion, p. 362.

later periods. We shall return to this subject, when adverting to the rocks of the so-called Primitive Slate formation.

With regard to the fluid part of the original globe, we have seen that it must have been made up, with but little exception, of the inorganic constituents of the earth's crust. It is evident, that in this fluid globe the heavier particles must have found their way to the centre, and that then, as now, the interior of the globe must have had a greater density than its surface. Indeed, the fact that this is the case at the present day is another proof that the globe must have been originally in a state of igneous fluidity, otherwise we could not account for the accumulation of the denser particles at the centre. In the same way as the densest particles were influenced by gravitation, so must also the fused silicates of different densities, and the metallic sulphurets and arseniurets have found their places in successive concentric zones, one beneath the other, according to their increasing specific gravities. Thus the theory of Sartorius von Waltershausen would appear to be as fully applicable when the earth was in a fluid state, as at the present time.

There is nothing unreasonable or inconsistent with the observations which we are able to make at the present day, in supposing the inorganic constituents of the earth to have once been in a state of igneous fusion. The various layers of fused material, to judge from the rocks resulting from their solidification, must have closeresembled in chemical composition the scoriæ produced in different blast-furnaces. If we suppose the uppermost highly silicified and consequently most difficultly fusible layer to be represented by granite, we find many instances of slags from iron-furnaces having almost as acid a composition. Many granites contain only 63 per cent. of silica, but those of the Hartz as high as 73.* On the other hand there are instances of iron-slags containing 70 and 71 per cent.† silica. So far as the other more basic layers and the rocks resulting from them are concerned, we can find their equivalents among the slags of iron, copper and lead furnaces, since the silica contents of the latter range from 70 through every percentage down to 8 p.c. If we continue the analogy, and suppose the properties of these slags, to correspond somewhat to those of the eruptive rocks having a similar chemical composition, we

* Bischof: Chemical and Physical Geology, III. p. 414.

† Kerl: Handbuch der Hüttenkunde, I. p. 323.

may find a clue to the explanation of the various forms of deposition, and other characteristics of the latter. Thus it is well known that the slags in which silica preponderates flow sluggishly and solidify slowly, while basic slags flow quick and hot and harden suddenly. It may reasonably be concluded, that the rocks of igneous origin would act similarly, and that consequently granites, porphyries and trachytes would be more viscid, and have better time for cooling and crystallizing, than the more basic greenstones, melaphyres and basalts. The greater frequency of impalpable and finely granular varieties among the latter rocks would be in this way accounted for.

We now proceed to consider what must have been the consequence of the gradual radiation of heat from the igneous globe. "I know of no mode," says McCulloch,* "in which the surface of a fluid globe could be consolidated but by radiation, while of the necessity of such a process I need not again speak. The immediate result of this must have been the formation of rocks on that surface; and if the interior fluid does now produce the several unstratified rocks, the first that were formed must have resembled some of these, if not all. We may not unsafely infer that they were granitic, perceiving that substances of this character have been produced wherever the cooling appears to have been most gradual. The first apparently solid globe was therefore a globe of granite, or of those rocks which bear the nearest crystalline analogies to it." To these utterances we must in the main assent, inquiring however whether the relations existing at the time of this first solidification might not have given rise to the formation of schistose granite or gneiss. Nothing is more conclusively established, than that there exists, at the present day, in the atmosphere and ocean, a series of currents, caused by or attributable to the diurnal motion of the earth. May not similar currents have been in operation in the fluid igneous material, during the first solidification of the earth's crust? Is it not possible that after this solidification had commenced, the outer shell may have moved quicker than the fluid interior, from east to west, and that the gradual accumulation of crystallized rock on the interior of the crust may have taken place under circumstances similar to those so well described by Naumann in referring to the parallel structure of certain igneous rocks? † There are not want-

* System of Geology, vol. ii. p. 417.

† Canadian Naturalist, vol. viii. p. 375.

ing instances of the formation of a slaty structure in artificially formed slags, from a similar cause. Nothing is more common than to observe in slags from iron-furnaces a distinct streaked or banded appearance, evidently caused by the different rate of motion in the interior and outside parts of the flowing stream of slag. This phenomenon I have often observed at the Eglinton iron-works, Scotland, and more recently at Bethlehem, Pennsylvania. It is simply another instance of the production of a stratified appearance, similar to those described by Tyndall in his work "On the Glaciers of the Alps." In this work he shows that the banded appearance of glacier-ice, the lamination of wax subjected to pressure, and the fibrous texture of rolled iron, are caused by the motion under pressure of the atoms constituting those substances. Not only has a banded structure been observed among certain furnace scoriæ, but the latter have even been observed to possess sometimes both fibrous and foliated structures. The raw slag from the "Frischfeuer" at Bieber in Hessia, possesses a marked fibrous texture, and slag with a distinct slaty texture is produced at the blast-furnace in Mägdesprung. The latter is formed swimming on melted iron, while its surface comes in contact with the cold air. Small pieces of this slag resemble the refuse of roofing slate, not only in their appearance, but also in their cleavage. In larger pieces perfectly vitreous layers are combined with the slaty ones, both graduating into each other.* From these instances, and considering that the existence of internal currents at that period is highly probable, it would appear not unreasonable to expect that some of the rocks solidified on the surface of the fluid globe, would have a schistose structure. It is impossible to suppose that the particles of the fluid material beneath the solidifying crust, would always preserve the same relative position to the latter, in spite of the daily revolution of the globe. The liquid rock beneath the crust must have moved in one direction or other almost as freely as the water of a frozen river under the ice which covers it. The schistose structure resulting from this solidification under motion must however have resembled more the foliation of certain igneous rocks than the stratification of sedimentary strata. The stratification of gneiss and gneissoid rocks has not unfrequently been denied. Thus Featherstonhaugh declared, that "what has been called the stratifi-

*Von Leonhard, Hüttenerzeugnisse und andere auf künstlichem Wege gebildete Mineralien als Stützpunkte geologischer Hypothesen, p. 156.

cation of these igneous rocks, may be owing to the principle which occasions their fissility." Coquand regards gneiss as a "granite stratoïde, mais non stratifié."* Rivière opines also that gneiss does not form true layers, but is only a fissile or pseudo-stratified rock.† Even McCulloch makes the following admission: "Gneiss has not yet indeed presented any decided marks of that mechanical arrangement which so often occurs in the other stratified rocks; since I must explain the parallelism of the mica, which has been supposed a proof of such arrangements, in a very different way. In hypersthene rock, an unstratified member of the trap family, the crystals of that mineral often occur in a similar laminar manner, so as to communicate a fissile tendency to it; and in Kerrara mica itself is thus found not only in a mass of trap, but in a vein of the same substance, with the same parallelism to the sides of the vein as it has to the plane of the stratum in micaceous schist."‡ The idea that gneiss may have been formed in the manner above indicated is not entirely new. In 1845 it was stated that the gneiss of the Saxon Erzgebirge "perhaps differs only from granite because it solidified under the influence of certain pressures or tensions.||

Whether the explanation here attempted of the parallel structure of gneiss may be regarded as adequate or not, it does not at any rate seem to be any more far-fetched than the theory which attributes this phenomenon to the influence of electric magnetic currents (Scheerer's theory) or even than that which regards gneiss as a sedimentary rock, altered in some obscure manner by heat or other agencies. Besides the arguments given above in support of the first mentioned view, there are also some general considerations in favor of the existence of a primitive formation, which are stated as follows by Naumann.§ "The oldest sedimentary formations must have had some material from which they could be formed, and a foundation on which to be deposited. The whole series of sedimentary formations must have been borne by something, and the material of at least the first member of this series must have been derived from something, which something cannot be assumed to be the result of a sedimentary operation."

* Bull. de la Soc. Geol. tome ix. 1838, p. 222.

† Compte rendus, tome xxv. 1847, p. 898.

‡ System of Geology, Vol. II. p. 152.

|| Geognostische Beschreibung des Königreiches Sachsen, 2tes Heft, p. 122.

§ Lehrbuch der Geognosie, ii., p. 8.

"In the same way there must have existed a covering through which the oldest eruptive formations were protruded, and a foundation upon which they could spread themselves out; and the whole series of eruptive rocks must, like those of sedimentary origin, have at the commencement been borne by something which cannot be regarded as the result of an eruptive operation."

"We find ourselves thus obliged, from two sides, to assume the existence of an originally existing solid crust of the planet, which formed the theatre and the foundation for all the later formations, above and beneath which those two energies in nature could develop themselves; through which on the one side the sedimentary, and on the other side the eruptive formations were brought into existence; and that formation of which this original foundation consisted it is consequently proper to entitle the primitive or themelian, the original or fundamental formation."

"To this formation those enigmatical, deepest-lying rocks belong which resemble sedimentary strata, in possessing more or less perfect stratification, and which resemble eruptive rocks, when their mineral composition and their crystalline structure are taken into consideration; but they are devoid of the fragmentary rocks and the organic remains by which the sedimentary formations are characterized, and on the other hand do not possess the veins, masses and streams common to eruptive rocks, nor the abnormal relations of these at their junction with other rocks. In a word, we meet in the primitive formation many of those rocks which we have above designated cryptogenous, such as gneiss, mica schist, hornblende-schist, etc.; rocks whose unaltered character we are not justified in denying in every case, merely because in some cases similar rocks have been formed by the metamorphosis of sedimentary strata, or in an eruptive manner. Those who, because a few beds of mica-schist or gneiss have been admitted to be metamorphosed clay-slate or greywacke slate, declare that all mica-schists and gneiss are only altered sedimentary rocks, only metametamorphosed beds of mud, virtually remove the ground from beneath our feet, and limit us to a transcendental succession of sedimentary deposits, which, downward, has no end, or rather no demonstrable commencement; because finally the actual sedimentary origin can neither be recognized nor proved, but can only be maintained as a hypothetical assumption."

"The primitive formation appears to possess quite an extraordinary thickness; and to reach very far down into the depths of the

earth. At the same time it shows in a remarkable manner, in those different regions where it comes to the surface, such a general resemblance as regards its rocks, their structure and form of stratification, that one is led from this alone to think that some stupendous process must have taken place over the whole surface of the earth at the same time and in the same manner, and that it is to this process that the primitive formation owes its existence; and even, although it may be so completely covered over in regions of immeasurable extent that in these it is not observed to come to the surface, still we are entitled with complete justice to suppose the existence of an uninterrupted extension of the same, under all the sedimentary and eruptive formations with which we are acquainted.

"The necessity of a primitive formation is besides so apparent that one can scarcely comprehend how its existence could ever be doubted. It appears, in fact, to be a first and indispensable condition, without which the possibility of sedimentary, as well as of eruptive formations cannot be comprehended. The primitive formation has also been, by different authors, entitled the prozoic, azoic or hypozoic formation, because it existed long before the commencement of the first races of animals or plants, and therefore contains not a trace of organic remains, and lies beneath all fossiliferous formations. But all eruptive formations are likewise azoic; the oldest sedimentary formation is likewise prozoic, and the term hypozoic is perhaps a word which does not correspond sufficiently well with the idea intended to be expressed by it."

"It is possible for us to regard the primitive formation perhaps, as the uppermost part of the original solidified crust of our planet; and this supposition has here and there been adopted. We leave, however, the process of their formation undecided, and rest satisfied, in the meantime, with the negative result, that according to the present condition of our knowledge, the primitive formation can neither be a sedimentary formation, in the usual signification of the term, nor yet an eruptive formation, properly speaking. It is however a most remarkable fact, that a few comparatively far younger formations show a surprising similarity to the primitive formation in the structure and architecture of their rocks, (viz., the Münchberg gneiss-formation in Oberfranken, and the protogine formation of the Alps). This fact, as well as the circumstance, that they are almost all cryptogenous or stratified crystalline rocks, which occur, on the one hand, as undoubted primitive, and on the other as newer products, make it advisable to class

both together under the common name of the cryptogenous formations, or also of the stratified silicate formations."

"Many, perhaps even the most of the geologists of the present day, are of the opinion that the strata of the primitive formation are very ancient metamorphic sedimentary strata. Until convincing proofs are adduced in support of this view, it may however, only be excused as an attempt to bring incomprehensible phenomena into unison, at least hypothetically, with comprehensible appearances. 'Whereupon,' asks Humboldt, 'do the oldest sedimentary rocks rest, if gneiss and mica-schist are only to be regarded as altered sedimentaay strata?' Cosmos, i., p. 299."

It is very evident from the foregoing, that Naumann leans to the opinion that the primitive formation is the result of the first process of solidification which the fluid globe underwent. He refrains from declaring himself in favor of this idea, principally on the grounds mentioned in another chapter of his "Lehrbuch," a translation of which has already been given in this Journal.* These grounds are the foliated texture of gneiss and its associated rocks, and the highly inclined position of their strata. The first of these phenomena I have already attempted to account for. We shall, in the course of the following remarks, endeavour to ascertain whether the almost vertical position of the primitive strata is also capable of being explained.

In regarding gneiss as an igneous rock, there are, of course, the same difficulties arising from its mineralogical composition, to be explained away, as in the case of granite, but these we intend to postpone considering, until we come to speak of the protrusion of the latter rock. The same mode of explanation adopted in the case of gneiss, would of course require to be resorted to in the case of the schistose rocks associated with it, especially such as mica-schist and hornblende slate. We must not suppose that the latter rock was formed from the same zone of igneous material as the gneiss, but on the contrary, that it is the product of some of the lower zones, brought up to the newly formed crust by cosmical influences, and consolidated on the inner part of the same, subject, of course, to the same influences during its solidification as we have supposed in the case of gneiss. We thus suppose that the first stage of the consolidation of the globe consisted in the

* Vol. vi., p. 254.

formation of a thin crust of stratified rocks; those rocks being now to be found constituting the so-called primitive gneiss formation.

In accordance with the views given in the second part of this paper, of the nature of the process of solidification at present progressing beneath the earth's crust, we must suppose that during the solidification of the first crust, a contraction of the volume of the originally fluid material took place. This view must be adopted on experimental grounds also. Bischof found, in casting a globe of basalt, twenty-seven inches in diameter, that in the centre of the mass, on cooling, a cavity had formed capable of containing half a pint of water. Further, at the Muldner smelting works, near Freiberg, stones are cast of the slag run out of the reverberatory furnaces. They are two feet long, one foot deep and one broad, and when broken after cooling, they are found to contain in the middle irregularly shaped cavities from three to five inches wide, the sides of which are covered with brilliant microscopic crystals.* From these instances it might be expected, that during the first solidification, a vacuum might, to some extent, have been formed beneath the crust of the earth. With the progress of the consolidation the dimensions of the vacuum must have increased, and the power of the crust to support the enormous pressure of the then existing atmosphere must have decreased. We may suppose that ultimately a point was reached, when the crust was unable longer to support the enormous load, and that it then gave way in various places, its fragments sinking down to the fluid interior and floating upon its surface. In this way the first great subsidence of the earth's crust may be reasonably supposed to have taken place. The area of the original globe having however decreased during the solidification, it would be impossible for the fragments of the crust to maintain their original horizontal position. Very likely also the still fluid material beneath the crust would protrude itself through between the fragments, thrusting them aside, and limiting still further the space occupied by the latter. The consequence of this would be, that the fragments would arrange themselves in positions more or less vertical, and, although some of them might still remain horizontal, still highly inclined positions would be the rule. We can even imagine how corrugations of the strata, such as described by Sir William Logan in Canada, and by McCulloch in

* Leonhard, Hüttenerzeugnisse, p, 186.

Scotland, could be formed under the influence of the various forces here at work. While great areas of the earth's crust must have been dislocated in this manner, it is quite possible that other great areas may have been able to preserve, throughout these convulsions, their originally horizontal position. That part of the fluid material which may have protruded itself through the fractured crust, we may reasonably imagine to have solidified somewhat out of the range of the internal currents, and to have produced the first erupted granites. We may further reasonably suppose that the same fluid material must have penetrated into the interstices between the various fragments of the original crust, and have solidified there. This fractured and re-consolidated part of the crust would then present exactly the same appearance, so far as the relations of the various rocks are concerned, as the primitive strata of Canada, Scandinavia, and the north of Scotland do at the present day. That is to say the strata of gneiss, granite, mica and hornblende schist would be arranged in highly inclined positions, and if in contact with rocks of later periods, the latter would overlie the primitive strata unconformably. This peculiar build of the primitive rocks is characteristic of those districts where they have been admitted to be the oldest rocks on the earth's surface. Thus, in some of the Western Islands of Scotland, the primitive strata are not overlaid by any newer rock; and in Canada the vertical strata of the Laurentian series are in many places covered by the horizontal beds of the Potsdam sandstone. In Norway the outcrops of the highly inclined primary strata frequently occupy areas of several hundred square miles, and, at the outskirts of these areas they are overlaid by fossiliferous strata of the Silurian system. The primitive rocks of Brazil, consisting of gneiss, gneiss-granites, granite, syenite, mica-schist, and hornblende rocks, extend north and south through fourteen degrees of latitude, and have a breadth of 250 geographical miles, in which enormous area, strata inclined from 45 to 70 degrees are alone observable. We cannot suppose that these rocks were originally formed in this position; nor can we reasonably regard them as a system of strata, having, in their original horizontal position, a thickness of upwards of 100 geographical miles. There remains only the explanation given above, that the originally not very thick strata assumed their highly inclined position owing to the lateral pressure to which they were exposed; the latter having been caused, partly by the contraction experienced by the globe in cooling, and partly by the protrusion of

igneous matter from beneath the broken crust. An analogous phenomenon may every winter be observed on the St. Lawrence. When the ice shoves, pressure being exerted upon it from higher up the stream, the floes of ice are raised upon their ends, and a confused aggregate of inclined beds is the result; and it is worthy of remark that each of these beds is in itself distinctly stratified, just as are the individual layers of the primary rocks, the cause of this stratification being in each case not entirely dissimilar.

We have thus endeavoured to remove Naumann's principal objections to the igneous origin of the primary stratified rocks. We have next to refer to the objection founded on the mineralogical composition of gneiss, which is the same as in the case of granite. This objection is the presence in it of quartz, which occurs in such a manner, as to indicate that it must have been the mineral which solidified last of all, although it is the most infusible of the constituents of granite. Perfectly well formed crystals of it often, it is alleged, leave their impression on the adjoining feldspar and mica. We have already seen that this is denied by Sartorius von Waltershausen, who also insists that the quartz formed subsequently to the consolidation of the granite, by the action of water, must not be confounded with the original granular quartz, which is never or seldom found crystallized. In spite, however, of this denial, many supporters of the igneous origin of granite consider it necessary to attempt to account for the occurrence of quartz in the manner above stated. The following are the remarks of Naumann on the subject: "Gaudin's experiments have shown that melted silica becomes viscid before it solidifies, and while in this state it may be drawn out into threads like sealing wax. This proves that the temperature, at which it solidifies, lies very far below the temperature, at which it fuses, wherefore this phenomenon has been used by Fournet in support of his theory of the surfusion of silica, the fundamental idea of which theory has also been strongly supported by Petzholdt (Fournet, Compte Rendu, tome xviii. 1844., p. 1050; and Petzholdt, Geologie, p. 313). Moreover Durocher has pointed out that the fusing temperature of silica (perhaps amounting to 2800 degrees C.) is not necessary in order to explain the crystallization of granite, because the silica of the quartz formed, combined with the elements of the feldspar and the mica, a completely homogenous, igneous magma, in order to the fusion of which a temperature approaching the fusing point of orthoclase may have been sufficient. While the feldspar and mica crystallized from

this magma, the excess of silica was merely *separated* as quartz.* These two explanations must not be confounded with each other. The surfusion of Fournet differs essentially from the viscosity of Durocher. "En vertu du premier," says the latter philosopher, "une substance peut conserver sa parfaite liquidité, à une température inférieure à son point de fusion. En vertu du second, des substances diverses, chauffées jusqu'à liquéfaction, puis abannonnées au refroidissement spontanné, dans les mêmes circonstances, mettent des temps fort inégaux à se solidifier, celles qui tendent à crystalliser, deviennent solides les premières; celles qui constituent des masses amorphes restent longtemps dans un état plastique analogue à celui de la poix et intermédiaire entre l'état liquide et l'état solide."† When we take into consideration the common blowpipe reaction, in which silica is often separated from a fused bead as a gelatinous skeleton, it would appear to lend considerable support to Durocher's theory.

I here conclude the explanation which I have attempted of the origin of the Primitive formation. I conceive that only one series of rocks is entitled to this appellation. The term primary has often been applied to quartzites and slates of later age; which rocks have been classified by German geologists under the name of the Primitive Slate formation. It is very evident, however, that there can have been but one primitive formation, and since the slates and quartzites above referred to bear evidence of their having been derived from pre-existing rocks, it would appear incorrect to entitle them primary or primitive. Were it not that geological nomenclature is already sufficiently confused, it would appear much more reasonable to apply the old term of Transition Formation to these rocks; since it is highly probable that during the period in which they were formed, the temperature of the first crust gradually decreased to a temperature at which it was possible for water to exist in large quantity on the earth's surface. We have seen that during the first granitic eruptions, water did not exist on the surface, otherwise rocks of a more or less tufaceous character would have been produced. This conclusion would also seem to be corroborated by the ideas which we must entertain of the high temperature of the newly solidified crust. When the temperature of the latter so far decreased as to admit of the condensation of the water existing in the atmosphere, the rain, which fell upon it, must

* Naumann, Lehrbuch, i., p. 740.
† Bul. de la Soc. Geol. 1849-50, p. 276.

have been instantaneously evaporated. This rapid condensation and evaporation must have continued through long ages before any considerable accumulation of water could have taken place. Even then such accumulations must have possessed for a long time a boiling temperature, and long ages must again have been necessary before it cooled down to such an extent as to enable animated creatures to exist within it. If to these considerations we add the following, namely that the water condensing upon the heated rocks must have been charged with muriatic and carbonic acids, (the latter at a later stage than the former), it is very plain that the products of the action of the atmospheric influences then, must have been of a character widely different from those produced by the same agencies at the present day. The action of such acidulated water aided by heat must have been much more energetic then than now. This has been already fully recognized by Dr. Hunt. "The solid crust," he remarks, "would afterwards be attacked by the acids, precipitated, with water, under the pressure of a high atmospheric column, and at an elevated temperature; from which would result the separation of a great amount of silica, and the formation of an ocean, whose waters would contain in the state of chlorides and sulphates not only alkalies, but also large portions of lime and magnesia. At a later period, the decomposition of exposed portions under the influence of water and carbonic acid would give rise, on the one hand to clays, and on the other to carbonate of soda. This latter reaction upon the calcareous salts of the seawater must produce chloride of sodium and carbonate of lime. We have here a theory of the source of the quartz, the carbonate of lime and the argillaceous matters of the earth's crust explaining at the same time, the origin of the chloride of sodium of the sea, and the fixation of the carbonic acid of the atmosphere in the form of carbonate of lime."* I may be permitted to remark, that no theory accounts more completely and satisfactorily for the origin of the so-called Primitive Slate formation, than does this. It is surely not too much to assume, that the crystalline character of its rocks has been caused by the nature of the agents then at work, and the influence of the higher temperature and greater atmospheric pressure then prevailing. It is evident that the action of the muriatic acid of the atmosphere *must* have long preceded the action of carbonic acid, since we are almost unable to conceive that the latter gas could exist in

*Canadian Naturalist, vol. vii., p. 202.

water of higher than ordinary temperature. The quartz, the carbonate of lime, and the argillaceous matter above mentioned are peculiarly at home in the Primitive Slate formation, and are comparatively rare in the fundamental gneiss or primitive formation-proper. We have only to refer to the highly quartzose rocks of the Huronian formation, of the Thelemarken quartz formation, and of the so-called primary sandstones of the western islands of Scotland, to show that the separation of quartz on an extraordinary scale must have been one of the first products of the condensation of aqueous vapour on the earth's surface. Moreover, although primary limestones are not of unfrequent occurrence in gneiss, they are of trifling extent compared with the limestones of the so called Primitive Slates. At first of less frequent occurrence, of light grey colour, and crystalline character, and evidently more the result of a chemical precipitation than made up of animal organisms, they pass through various gradations of color, becoming more frequent and of darker color (more charged with carbon) as they grow younger. In the micaceous and the clay slates, which exceed in extent of developement both quartzites and limestones, we find a similar gradual change in their colours and lithological characters; the younger they become the more they are charged with carbon, and the more they resemble slates of more modern formations. The source of this carbon was undoubtedly the atmosphere, where it probably existed free, or was derived from the decomposition of its compounds with other elements. During the period, when the primitive slate rocks were formed, the metallic chlorides were also most probably removed from the atmosphere. This may have given rise to the extensive metallic deposits existing among these crystalline slates.

After the abrasion of the material from which the quartzose, micaceous and argillaceous slates resulted, we must suppose that it became deposited in the hollows of the then existing crust, which hollows were most probably occupied by primitive strata lying horizontal or nearly so. Those parts of the first crust, which rose above this primitive ocean, are most likely to have been the highly inclined primitive strata or eruptive masses of granite. If this view be correct then the rocks of our Transition formation must generally have been deposited conformably upon horizontal gneiss, or rocks allied to it.

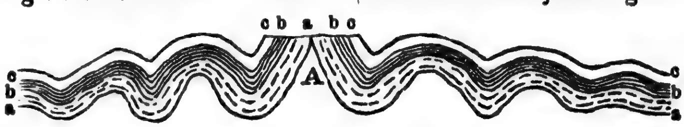
While the atmospheric agencies, and more especially water, were thus at work upon the surface of the original crust of the

earth, the same process of solidification which we formerly referred to, must have been progressing beneath it. The interior of the globe must have experienced a further contraction; and after having resisted for some time, the earth's crust must have subsided, and become fractured and folded in the same manner as the primitive gneiss, though perhaps to a less violent degree. This idea of a gradual contraction of the globe, and the consequent folding of the strata composing the crust, has especially been advocated by French geologists such as Rivière and Constant-Prévost. The latter geologist has the following remarks upon it: "Après des dissidences plus apparentes que réelles, presque tous les géologues tendent à admettre aujourd'hui, que l'enveloppe consolidée de la terre a éprouvé, et éprouve encore, un mouvement centripète contenu, dû à la diminution de chaleur et de volume de la masse intérieure du globe. De ce mouvement il résulte nécessairement, dans l'enveloppe solide, et après une résistance plus ou moins longue, des ondulations, des plissements, des redressements et des ruptures, dont les unes sont produites dans les parties enfoncées, et les autres dans les parties relevées des plis. C'est par ces pentes que sont sorties les matières encore molles sous-jacentes; elles ont traversé les issues qui leur étaient offertes, mais elles n'ont pas brisé les barrières qui les retenaient. Sans doute qu'avec ces mouvements généraux des rapprochements du sol vers le centre de la plauète, le refroidissement a produit des retraits locaux partiels dans les matières refroidies; que la diminution inégale des matières de nature diverse a également donné lieu à des changements relatifs de niveau et à des ruptures quelquefois très-importantes; que souvent aussi le plissement de tables horizontales a pu occasionner des pressions latérales qui ont poussé, de dedans ou en dehors, des matières malléables en sens inverse de celui déterminé par la grande cause première du mouvement, lesquelles matières ont pu redresser, renverser, soulever les lambeaux des strates brisées. Mais ce sont là des faits de détail, des exceptions qui, loin d'infirmer la loi générale, viennent la confirmer, lorsqu'ils sont analysés avec attention et réduits à leur juste valeur."* In describing and accounting for the architecture of the "Terrain gnéissique de la Vendée" Rivière adopts the same theory.†

* Constant-Prévost, sur le mode de formation des chaînes de montagnes. Bul. de la Soc. Géol. de France, 1849–50, tome vii, p. 53.

† Bul. de la Soc. Geol., 2 series, tome vii., p. 327.

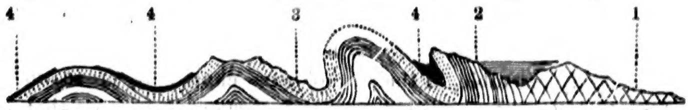
We may now proceed to consider what effects, according to this theory, would be produced on the earth's crust as the same was constituted after the slate rocks above mentioned, and even the so-called greywacke series had been deposited. The slates and sandstones of the latter formation are the oldest rocks which thoroughly resemble, in their lithological characters, the sedimentary deposits of later periods; wherefore we may suppose that at the same time they were formed, the temperature of the earth's surface and the agencies at work upon it somewhat approximated to those of the present day. The portion of the earth's crust least likely to be affected by the subsidences consequent upon the contraction of the globe, may reasonably be supposed to have been the thickest part, that part where vertical strata of gneiss and rocks allied to it, extended deep down into the earth's crust. The part most liable to be fractured and raised into folds, would most probably be the thinnest, or that part where horizontal or but slightly inclined gneiss strata, had been conformably overlaid by micaceous, argillaceous, chloritic and quartzose slates. If we attempt to speculate as to what might be the first consequences of the contraction upon these latter rocks, we would naturally suppose that after a fissure had once been formed, the strata bordering on it would rise in a manner sketched in the subjoined figure.



a. gneiss, b. mica schist, c. clay slate.

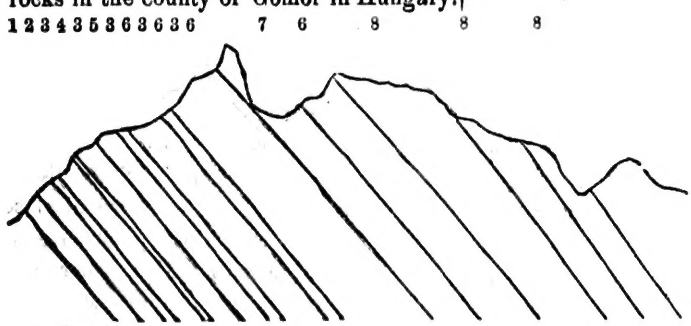
And in reality not a few of the so-called Primitive Slate districts possess an architecture closely analogous to the above ideal section. This is especially the case in the Alps of Salzburg and Upper Carinthia. In this part of the central Alps, according to Credner, a mass of granitic gneiss, drawn out from east to west, forms the centre. On the north as well as on the south side of this mass crystalline slates overlie it. On the north side the dip is at a high angle to the north, and on the south side the highly inclined strata dip to the south. These crystalline slates are divisible into three groups, the lowest consisting of common and calcareous mica-slate, the middle group of chlorite and talc slates, and the upper group of common and calcareous clay-slate. Moreover the structure of the metamorphic rocks of eastern North America, and also of the slate districts north of the Mjo'sen in

Norway, would seem greatly to resemble the above ideal section, if we suppose one half of the same to be obliterated. The following is a section of the Alleghany chain according to Rogers:*



1. Gneiss, mica slate, &c.
2. Silurian system (so-called metamorphic strata).
3. Devonian "
4. Carboniferous "

The above delineated structure of the slate rocks would have experienced a modification, in the event of igneous rocks having been protruded through the fissures formed by these movements of the earth's crust. These igneous rocks would most easily be protruded at the point marked A in the sketch first above given. If we imagine a granitic mass to be erupted at the point so marked, we have then a section resembling in its general features the build of the so called primitive rocks in many parts of the Alps of Switzerland, in the Saxon Erzgebirge, in Hungary, and in the gneissoid region of La Vendée, above mentioned. The following is a section given by Beudant, of the structure of the schistose rocks in the county of Gömör in Hungary.†



1. Granite.
2. Gneiss.
3. Mica-schist.
4. Greenstone.
5. Limestone.
6. Clay-slate.
7. Iron ore.
8. Schistose greywacke and limestone.

Here the primitive and slate strata rest upon the granite in the following order: 1st gneiss, 2d mica-schist, 3d clay-slate. The

* Naumann, Lehrbuch, i, 994.

† Voyage en Hongrie, Atlas, Fig. 5.

mica-schists and clay-slates in the districts above mentioned never occur overlying the gneiss strata unconformably. On the contrary, they are so intimately connected that a gradual transition is generally observed to take place between them; the gneiss gradually changes into mica-schist, the latter gradually becomes less crystalline, and finally argillaceous and chloritic rocks result.

A further modification of the above type of the structure of the slate rocks occurs when the granite is so extensively protruded as to overlie the gneiss strata, or when the latter have not been forced up to the surface. In this case the micaceous or argillaceous slate is found immediately reposing upon or at least in contact with the granite. In this manner the mica-schist with interstratified limestones, north of Drontheim in Norway, overlie the granite of Vestfjord, and in this way also the killas or clay-slates of Cornwall lean upon the granite of Dartmoor. In the latter cases no lithological transitions are observable between the slates and the granite, while in former cases, where gneiss is interposed between them, the transition from the latter rock to granite is distinctly observable. This phenomenon, it will be observed, however, is not inconsistent with the explanation here given of the origin of these rocks.

I have thus attempted to explain some of the most remarkable phenomena connected with the primary rocks. It will be observed that in so doing, I have tried to elaborate and combine together many of the ideas expressed by different geological authorities. I am far however from maintaining that the theory here given is adequate to account for all the facts observable in connection with these rocks. Nor is it at present necessary that this explanation should be perfect. There must be in geology as in other sciences, obscure problems always awaiting solution. The best apology which I can offer for presuming to attempt an explanation of the enigmatical phenomena connected with the primary rocks, is in the following words of McCulloch:* "The human mind is so constituted that it cannot rest content with facts. If it posesses innate propensities, the investigation of causes is assuredly one of them. The very geologist who disclaims all theory has his own; the lowest of the vulgar desire reasons. The laws which govern the phenomena of nature force themselves irresistibly on our attention. They are strictly involved with the analogies which regulate all our reason-

* System of Geology, vol. i, p. 485.

ings and direct our observations; and without them we cannot proceed a step on firm ground. They distinguish the philosopher from the empiric, and combine scattered observations into a body of useful and rational science. Even in the science of nature, as in that of numbers, the assumption of imaginary or erroneous laws, leads to the discovery of the truth. The history of astronomy is in itself a lesson to those who ignorantly undervalue the pursuit of general laws. Bewildered in spheres and vortices, it arose, as in a moment, complete, from the theory of gravitation.

"Hence the consideration of secondary causes, forms, not only a legitimate, but an essential part of geological science. That science, like all others, comprises the history of all the facts which it involves; and from these, it establishes certain general analogies. Ascending a step higher it declares the laws which have regulated, and will continue to regulate, all the phenomena of the globe; and thus finally establishes a legitimate theory of the earth."

No trace of organic remains has been discovered in these micaceous, chloritic or argillaceous slates, nor even in the limestones associated with them. The adherents of the metamorphic hypothesis attempt to account for this by supposing that the fossils have been obliterated by the agencies which have effected the alteration. But even in the greywacke slates and sandstones, traces of life are rare; and it is only in the very newest strata of that series, that they become at all frequent, and then they belong to the inferior grades of animal organisms. That the air-breathers, recently described by Dr. Dawson, first make their appearance in the coal-measures, may be regarded as a proof of the absence of free oxygen from the atmosphere which existed during the deposition of the Lower Silurian rocks. Not until the carbonic acid was to a great extent removed from the atmosphere by the luxuriant vegetation of the coal period, and its place taken up by oxygen, was it possible for air-breathers to exist. The extraordinarily rich vegetation of that epoch was no doubt stimulated by the immense quantities of carbonic acid in the atmosphere, and the exceedingly warm climate which then prevailed over the whole surface of the earth. This warm climate, we are justified in supposing, was caused more by the radiation of heat from the interior of the earth, than by solar influence. So that it is possible to trace a connection between the phenomena of internal heat

and the characteristic strata of the carboniferous system, and between that series of rocks and the constitution of the primitive atmosphere. In this, as in much of what has been stated in this paper we recognise how intimately linked together all natural phenomena and all departments of science are. The various natural sciences are like the crystalline rocks; they graduate into each other, forming, when properly interpreted, a compact, well ordered and harmonious whole.

And while we study and recognise all this, surely it behoves us to acknowledge reverently the great Author of all. The mere external features of primitive districts inspire us with feelings of wonder and awe. Standing on the summit of Gaustafjeld, we can look northward over hundreds of square miles of primitive rocks, forming there the broad, barren plateau of Hardangerfjeld. As far as the eye can reach there is spread out a desert of rocks broken only by the lakes, which form the sources of the turbulent streams that leap down into the fiords of the west and south, or by valleys with precipitous sides, which seem as if hewn out of the solid rock of the plateau beneath the level of its general surface. The scanty and stunted vegetation heightens the desolation of the scene, but nevertheless its rugged grandeur causes the observer to be deeply impressed with his own insignificance, and with the awful power of the Originator of the universe. But how greatly is this feeling deepened when the architecture of these rocks and the mode of their formation is considered. Here we feel our utter littleness even more forcibly; but we at the same time gain some idea of that series of processes and revolutions by which the earth was fitted for man, and of the power and wisdom of the great Designer who caused our present beautiful earth to emerge from the chaos of the primitive period. We also learn enough to exclaim with the Psalmist, "Of old hast Thou laid the foundations of the earth."

Acton Vale, C. E.

12th January, 1864.